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M.W. Horn, C.F. Stewart, R.L. Boulware

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16. ABSTRACT

Experience with piling for highway structures has indicated a need for positive anchorage of piles to the substructure to resist uplift forces. Six types of pile anchor device, two for use with steel piles and four for use with timber piles, were cast in concrete blocks designed to simulate bridge footings and tested using both static and cyclic loads to determine the pull out capacity of the pile to footing connection. The results from each anchor were compared with the desired allowable load capacity of 40% of the pile bearing capacity and also with the results from a comparable steel or timber pile control specimen that was identical to the test specimen in all respects except that it contained no anchor device. It was found that the control specimens together with one of the anchor types were subject to sudden failures near their ultimate load. All of the other anchors consistently sustained loads near their ultimate and had load capacities greater than the corresponding control specimen and greater than the corresponding control specimen and greater than 40% of the bearing capacity of the corresponding pile type. Except for one anchor type, all anchors were capable of resisting at least 100 cycles of loading (at a 0.1 cps load rate) from 0 kips to a load equal to 40% of the bearing capacity of the pile. All anchors that were reloaded statically after cyclic loading demonstrated static reload capacities in excess of 40% of the bearing capacity of the pile.

17. KEYWORDS
Pile anchors, steel piles, timber piles, uplift on piles, pile foundations, pile caps, pile footing, anchorages, pile connection

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CAPACITY OF PILE ANCHORS

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16. Abstract

Experience with piling for highway structures has indicated a need for positive anchorage of piles to the substructure to resist uplift forces. Six types of pile anchor device, two for use with steel piles and four for use with timber piles, were cast in concrete blocks designed to simulate bridge footings and tested using both static and cyclic loads to determine the pull out capacity of the pile to footing connection. The results from each anchor were compared with the desired allowable load capacity of 40% of the pile bearing capacity and also with the results from a comparable steel or timber pile control specimen that was identical to the test specimen in all respects except that it contained no anchor device. It was found that the control specimens together with one of the anchor types were subject to sudden failures near their ultimate load. All of the other anchors consistently sustained loads near their ultimate and had load capacities greater than the corresponding control specimen and greater than 40% of the bearing capacity of the corresponding pile type. Except for one anchor type, all anchors were capable of resisting at least 100 cycles of loading (at a 0.1 cps load rate) from 0 kips to a load equal to 40% of the bearing capacity of the pile. All anchors that were reloaded statically after cyclic loading demonstrated static reload capacities in excess of 40% of the bearing capacity of the pile.

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It is to be understood that the performance given for the various anchors tested are based on the conditions of this test and do not necessarily reflect their performance under other conditions. The reference to commercial anchors in this report does not in any way constitute endorsement of specific materials to the exclusion of equal products, nor shall any part of this report be used for advertising or promotional purposes.

The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CAPACITY OF PILE ANCHORS

December 1972

INTRODUCTION

Experience with piling for highway structures has indicated a need for positive anchorage of piles to the substructure to resist uplift forces. Specific instances where positive pile anchorages would have prevented severe structural damage are the following:

(1) Large lateral earth pressures pushed piling out from under abutment diaphragms,

(2) Flood waters exerted sufficient pressure on the bridge to cause overturning,

(3) Earthquake cyclic forces caused pile pullouts.

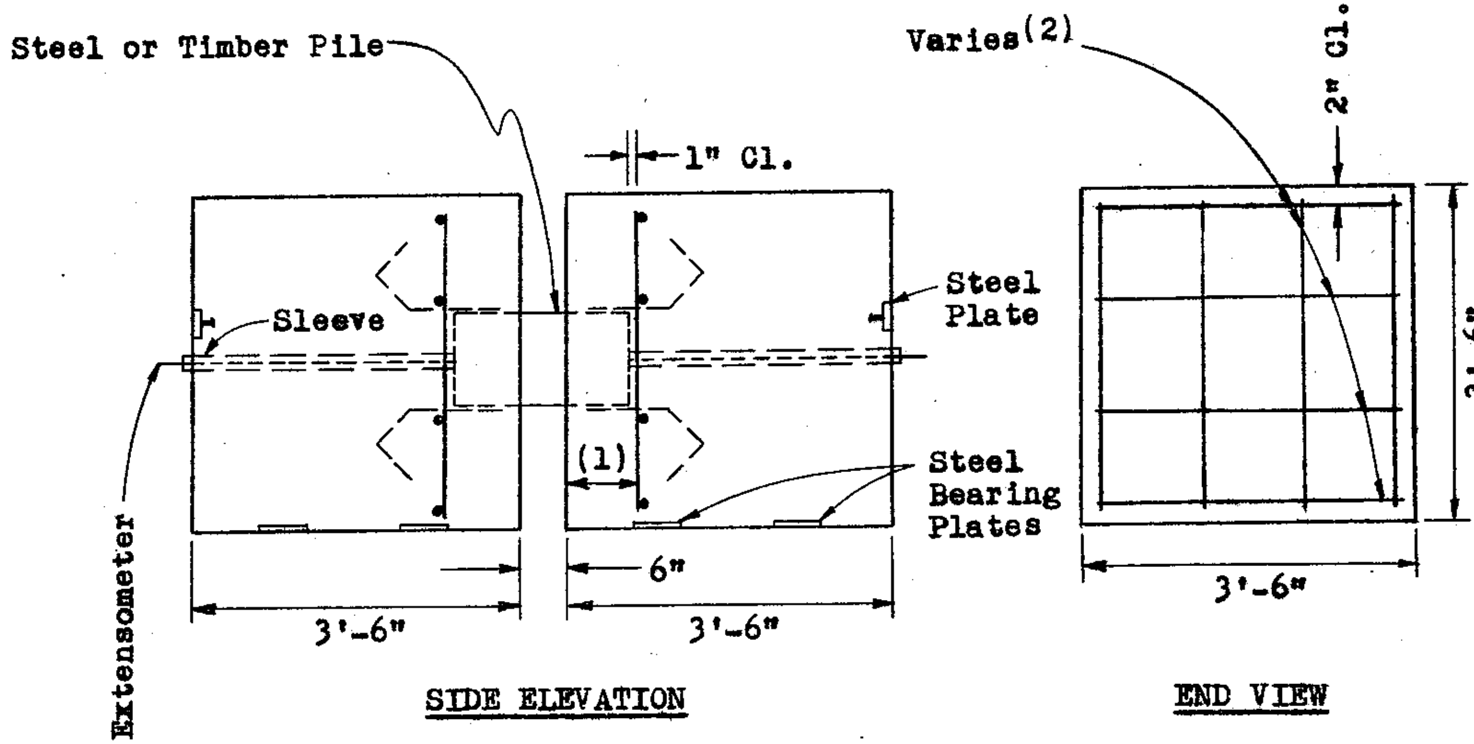
To overcome these problems the Bridge Department has designed several anchors for use with both steel and timber piles based on a capacity arbitrarily set at the same ratio as for design horizontal earthquake forces. In addition, at least two other anchors for timber piles were found to be available commercially. The estimated costs of known anchors were found to vary considerably, ranging from approximately \$4.50 to \$29.50 each installed, depending upon their complexity. Each of 6 types of pile anchor was tested to failure to determine its capacity to resist uplift forces on bridge footings and to learn whether the lowest cost anchors could be safely used.

PROCEDURE

The test procedure consisted of attaching the same type anchor to each end of a short pile section and casting a simulated concrete footing block around each anchor. See Figures 1 & 2.

The dumbbell shaped specimens were cast and loaded in a horizontal position rather than vertical primarily for convenience to avoid such problems as complications with forming, concrete placement and removal of the specimens after testing; having to account for the dead load of the upper block; and difficulty in locating and reading the slip measurement gages. To minimize horizontal sliding friction as the specimens were loaded, each block rested on two steel pipe rollers with steel bearing plates on top and bottom as shown in Figures 2 and 3. The lower pedestals were cast to provide a level surface for the bearing plates. Each roller was cleaned of concrete grout before testing was begun.

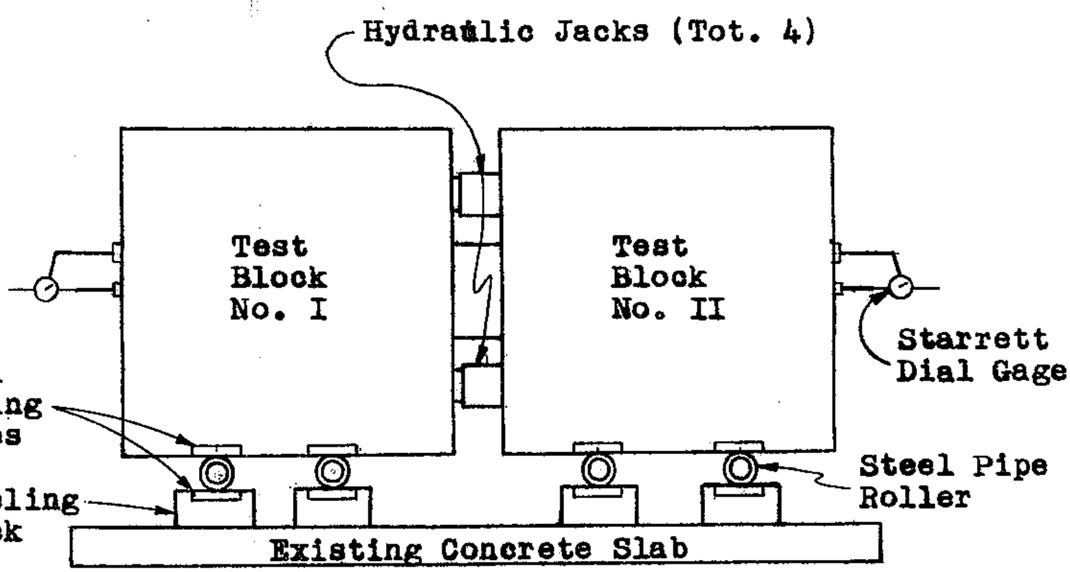
Eighteen specimens containing pile anchors and two without anchors were tested. The two specimens without anchors, one with a steel and one with a timber pile, acted as controls. They were fabricated to the same specifications as the eighteen prototypes except that the anchors were omitted.



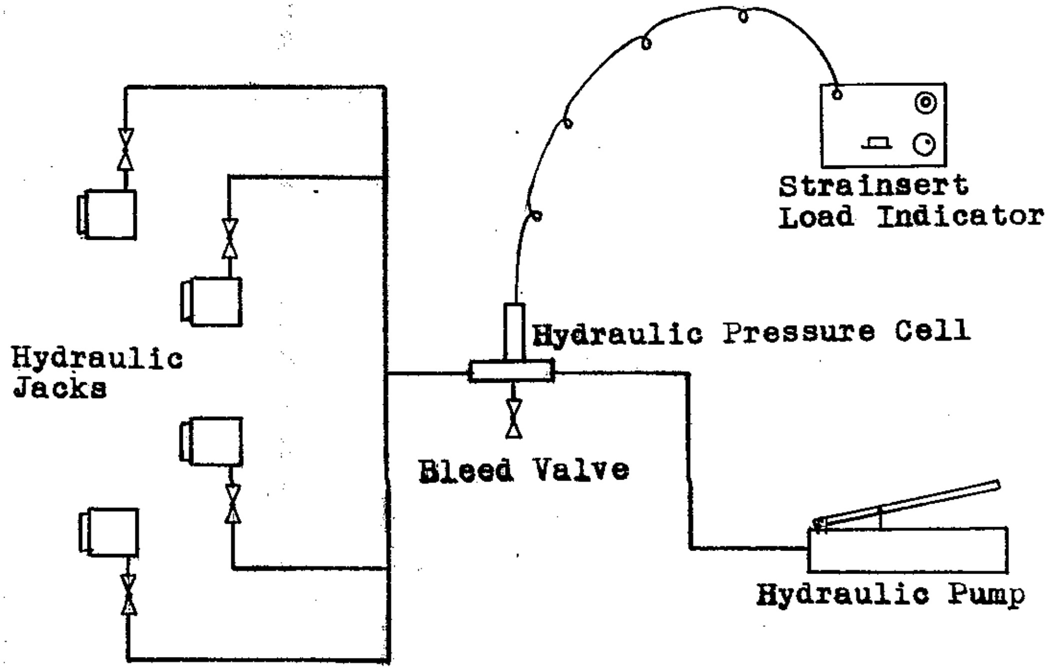
(1) Dimension varies. See pile anchor detail sheets.
(2) #8 or #11 bars. See text for details.

TYPICAL PILE ANCHOR TENSILE TEST SPECIMEN DETAILS

Figure 1



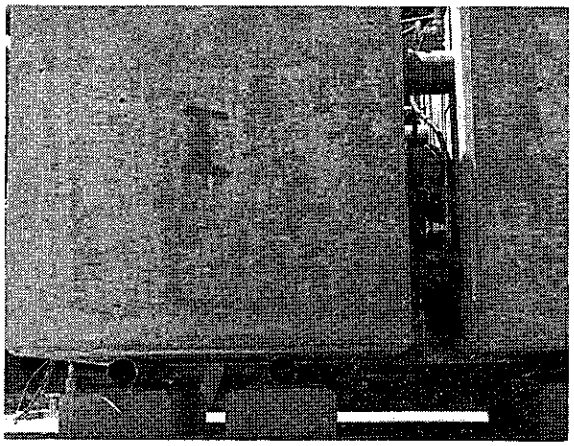
PILE ANCHOR TENSILE TEST SET UP



HYDRAULIC LOADING SCHEMATIC

Figure 2

Casting the Test Specimens



Pipe Rollers and Bearing Plates

Figure 3

The twenty specimens were fabricated and tested in 3 groups. Groups A & B contained 6 specimens each and Group C contained 8. Specimens in groups A and C were loaded statically, i.e., the load was increased in increments and the slip at the top of the pile recorded at the end of each load increment. The primary differences between the specimens in group A and group C were concrete age and compressive strength at the time of testing. Of secondary importance was the size of the reinforcing steel bars used to simulate the footing reinforcement. The specimens in group B were tested cyclically, i.e., loads were cycled 100 times between zero load and certain pre-selected successively increasing maximum loads. This group was purposely tested when the concrete age and compressive strength corresponded to those of group A so that the results of the static and cyclic loading conditions could be compared.

Table 1 is a summary of the various construction variables and loading conditions for the twenty specimens tested.

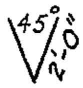
Test Group	Anchor Types	Reinforcement Mat (Each way)	Average Concrete Compressive Strength	Concrete Age	Loading Type
A	1-6	4 #11	4110 psi	20 days	static
B	1-6	4 #8	3920 psi	19 days	cyclic
C	1-6	4 #8	3490 psi	7 days	static
C	none (controls)	4 #8	3490 psi	7 days	static

Summary of Test Variables

Table 1

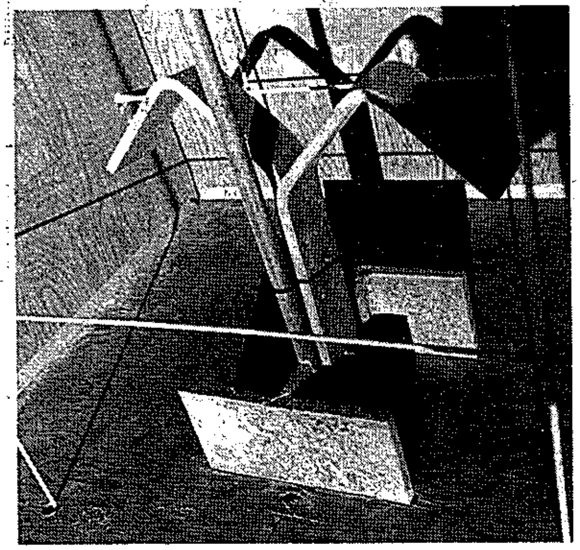
Photographs of the various pile anchors are shown in Figures 4 and 5. Details are shown in Figures A-5, A-10, A-15, A-20, A-25 and A-30 of the Appendix. A brief description of each anchor type follows:

Type No. 1 is for steel piles. It consists of 2 3"x1/2"x2'-0" steel plates bolted to the pile web with a single high strength bolt to provide a friction type connection.

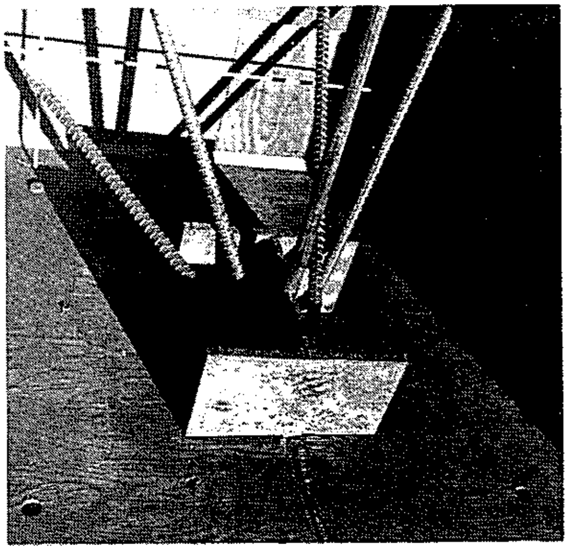
Type No. 2 is for steel piles. It consists of 2 #6x4'-0" concrete reinforcing steel bars (

) inserted through two flame cut holes in the pile web.

Type No. 3 is for timber piles. It consists of 4 3"x1/2"x 2'-0" steel plates bent into a hook shape and bolted to the end of the pile with a single bolt attaching opposite plates.



Pile Anchor Type No. 1



Pile Anchor Type No. 2
(Not Yet Tied in Place)

Pile Anchor Type No. 3
(Note Extensometer Detail)

Figure 4

Type No. 4 is for timber piles. It consists of 4 3"x1/4"x2'-0" steel plates bent into a hook shape with each plate fastened to the end of pile with 33 hardened rectangular nails (similar to dock spikes) driven through prepunched holes in each plate.

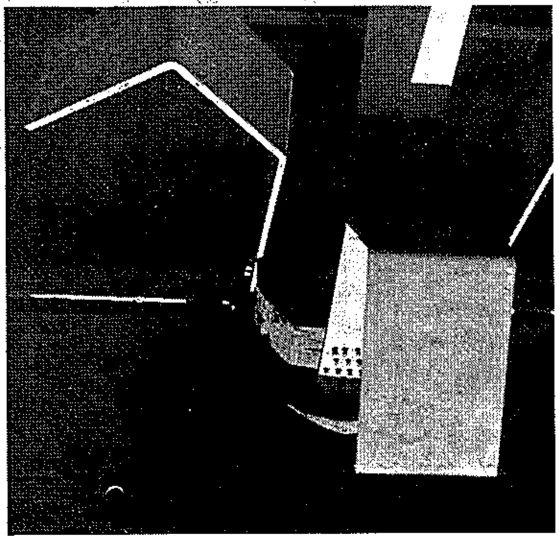
Type No. 5 is for timber piles. It consists of 2 #4 loop ( ) and 4 #6 hook (2'-0") concrete reinforcing steel bars placed around a tapered notch at the pile's end.

Type No. 6 is for timber piles. It consists of 2 2'-6"x3/4" hooked rods extending through holes drilled at an angle in the pile end and fastened at its side with a nut.

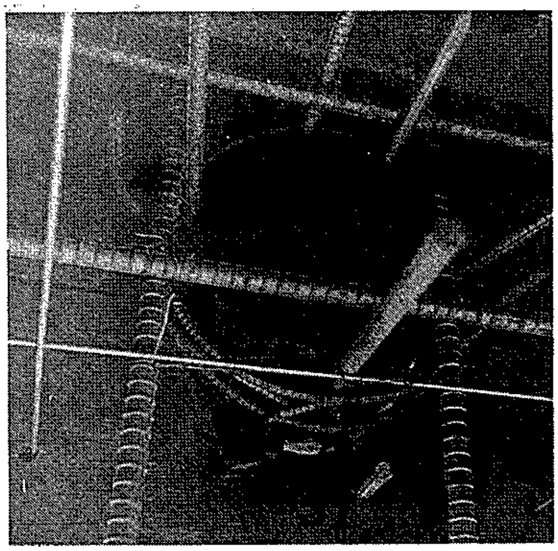
Anchor Type Nos. 4 and 6 are patented anchors.

Concrete used in the test specimens was a standard mix that was being used on the construction project where the testing was performed. The concrete mix contained 6 sacks of cement per cubic yard of concrete and 1" maximum size aggregate. The mixing procedure and all materials in the concrete mix conformed to the 1971 California Standard Specifications. Concrete was cured with pigmented chlorinated rubber curing compound.

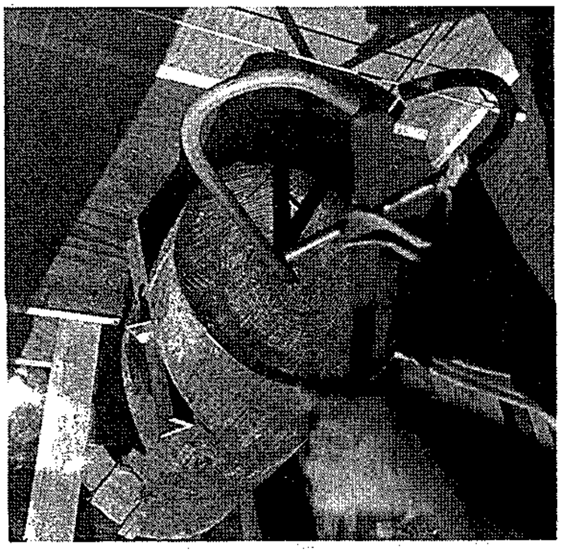
At least six concrete cylinders were fabricated for each of the three test groups as an aid in predicting concrete strengths. Two concrete cylinders were tested on the



Pile Anchor Type No. 4



Pile Anchor Type No. 5
(Note That the Footing
Reinforcement Has Been
Placed)



Pile Anchor Type No. 6
(Variation No. I)

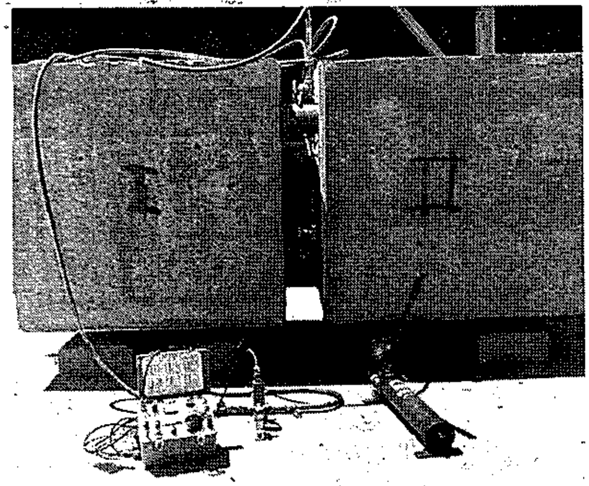
Figure 5

same day that the pile anchor specimens were tested and the average of these two tests are the values shown in Table 1.

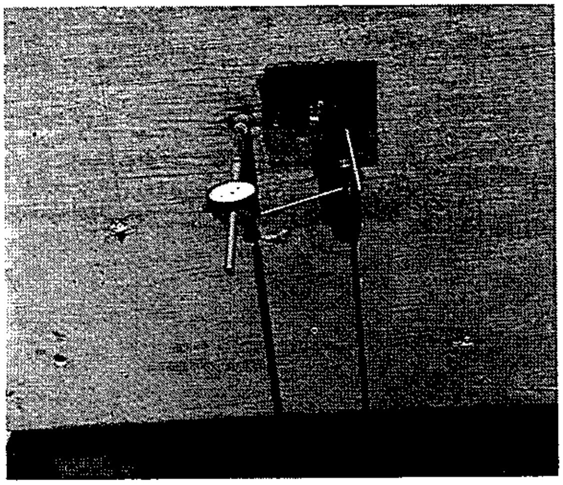
Loading of the pile anchor specimens was accomplished by means of four Duff-Norton RAM-PAC RC-50-H-4.7 fifty ton hydraulic rams connected to maintain equal hydraulic pressure on all four rams. The load was applied manually using a Duff-Norton HP-50 pump. Details of the test setup and a schematic of the hydraulics are shown in Figure 2. Figure 6 contains a photograph of an actual test setup. Each ram was located along a diagonal of the cross section of the concrete blocks a distance of 13.5 inches from the centroid of the pile.

The total load on each specimen was determined indirectly by a hydraulic pressure cell inserted in the line and monitored by a Strainsert indicator calibrated to read in pounds per square inch. This instrumentation is normally used by the Bridge Department Construction personnel to check loads in prestress tendons. It is shown in Figures 2 and 6.

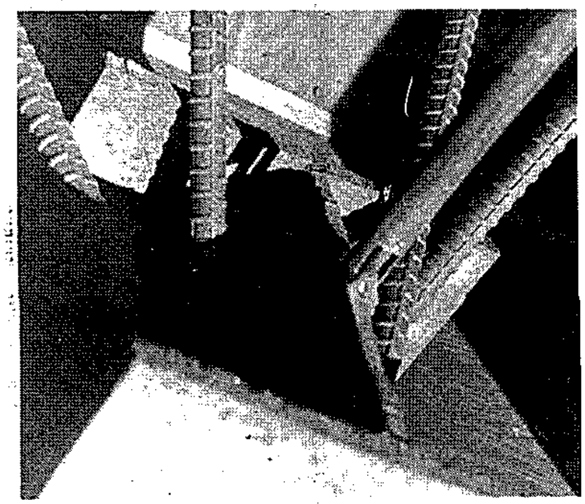
Slippage between the top of the pile and the unloaded end of the concrete block was measured directly using Starrett dial gages accurate to 0.0001 inch. Details for the dial gage set up are shown in Figures 1 and 2 along with a photograph in Figure 6. The gage was attached to the concrete block by means of a steel plate imbedded in the concrete block and a magnetic base. A 1/4 inch rod firmly



Pile Anchor Test Setup Showing Hydraulic Rams, Manual Pump, Hydraulic Pressure Cell and Strain-sert Load Indicator



Dial Gauge with Magnetic Base for Recording Slip Measurements



Detail of Pipe Sleeve and Extensometer Connection to Steel Pile

Figure 6

attached to the top of the pile and separated from the concrete block by a pipe sleeve served as the connection between the dial gage and the end of the pile. Figure 6 shows the detail of the pipe sleeve and extensometer connection to a steel pile. In the figure the sleeve has yet to be lowered over the pile web and calked. Similar details for the timber pile extensometer connection are shown in Figure 4 with the pipe sleeve removed. For the static loading condition, slip readings were taken after the application of each load increment. When cyclic loadings were applied, slip readings were recorded at least at the end of each 25, 50, 75 and 100 cycles of each load range.

RESULTS

The data from each of the twenty test specimens are presented graphically in various figures of the Appendix as measured slip vs. applied load. See Figure A-6 for an example. For the static load tests the curves in these figures represent the average slip of the two ends of the specimen at each applied load. Where results from the two ends of a specimen begin to diverge during yielding, the curve is shown as a dashed line. Straight dashed lines returning to the horizontal axis were used to indicate that slip measurements were made after the removal of all loads from the specimen. It will be noted that in several cases the final measured slip after load release is greater than the measured slip with the final load applied. In these cases the slip at the final load was measured immediately after the load was attained, and the slip continued to occur as the load was maintained before load release. Separate curves were plotted for the data from each end of Specimens 6A and 6C because slightly different variations of Anchor Type No. 6 were installed at either end of these specimens.

The data from the cyclic load tests (Test Series B) were presented in a slightly different form than the static load data. Again applied load vs. measured slip was plotted, but in this case the maximum load for each successive 100 cycles of loading is plotted vs. the average slip at the two ends of the specimen at the completion of the 100 cycles, both with the load applied and the load released. Except where noted, each 100 cycles of loading is represented by a solid straight line between the abscissa and the maximum load in each cyclic load range. Slip values at each end of the line are the averages from both ends of the specimen, and load release is again shown by a straight dashed line. Slip readings were also taken at the completion of 25, 50 and 75 cycles of loading, but these values are not shown. The curves showing the static reloading of the cyclic test specimens are plotted in the same manner as those for the A and C test series.

For comparison purposes and as a supplement to the graphs in the Appendix, the applied loads at various selected slip values are shown in Table 2 for each of the statically loaded specimens and for the cyclically loaded specimens during static reloading. As noted in the table, the ultimate strength and the load at 0.10 inch slip were estimated in several instances because either the loading was terminated near this value or only one end reached 0.10 inch slip. The loads at the slip of 0.01 inch had to be estimated for the two control specimens (7C and 8C) because of the large difference in behavior between the two ends of the specimens in this slip range. Since in all cases except specimen 5C the results from each end of each specimen agree quite closely, the load values in the table are those obtained from the curves in the Appendix. Both the maximum and minimum values rather than the curve value are shown for Specimen 5C.

Specimen No.	Loads (Kips) at Various Measured Slips 0"	0.001"	0.010"	0.100"	Ultimate	
7C (Control)	30	45	52	--	60	
1A (Static)	36	46	61	58	62*	Steel Pile Anchors
1B (Reload)	--	46	71*	--	76	
1C (Static)	30	44	81	91	91	
2A	41	50	79	130+*	130+*	
2B	--	22	112*	--	138+	
2C	37	49	83	--	116+*	
8C (Control)	29	29	24*	--	29	
3A (Static)	35	40	47	67	69	Timber Pile Anchors
3B (Reload)	--	57	64	78	86	
3C (Static)	27	33	49	--	69	
4A	25	45	91	121+*	151+*	
4B	--	76	90	142*	142+*	
4C	25	34	56	--	120	
5A	24	34	51	63	63	
5B	--	--	--	--	--	
5C (Max)**	29	37	62	--	76	
" (Curve)**	11	24	52	76*	76	
" (Min)**	5	17	42	--	76	
6A-I	19	27	45	48	48	
6B-I	--	10	53*	--	55	
6C-I	30	33	33	--	33	
6A-II	34	42	47	--	50	
6B-II	--	15	--	--	55+	
6C-II	16	24	31	--	32	

* Estimated Value.

** There was a large difference between the slips obtained at the two ends of this specimen, hence the range of values is shown.

SUMMARY OF LOADS AT VARIOUS SELECTED SLIP VALUES

Table 2

Numerical summaries of the cyclic load test data are shown in Tables 3 and 4. The odd load ranges shown are the result of using even increments of hydraulic line pressure for convenience during loading and then correcting later for jack friction and ram area using the calibration results. Due to the single valve limitation of the hydraulic rams used in the tests, the cyclic loads had to be applied manually. This accounts for the variation in average load rates shown in the table; as the investigator's pumping arm became weary, load rates tended to decrease as maximum applied load increased. The load rate in the tests was considerably less than the originally planned 1 cps rate.

At least one specimen for each type of anchor device was jackhammered apart to determine the mode of failure of the anchor device itself. There was no visible evidence of connection failure apparent in any of the anchors. Even anchor type No. 4 showed no visible evidence of connection failure although popping noises were heard while loading, as though each nail were failing. Any visible evidence of internal failure of the concrete around the anchor was, of course, destroyed during the jackhammering process. Nearly all specimens appeared to have a common initial failure pattern, as determined by examining the face of each concrete block. See Figure A-3. The concrete around the pile and the anchor combined to resist the load until the concrete around the pile failed in shear, at which time the anchor assumed all of the loading until it failed, as evidenced by continuous measured slip without appreciable increase in applied load.

Table 3

SUMMARY OF CYCLIC LOAD TESTS ON ANCHORS FOR STEEL PILES

Specimen	Load Range (Kips)	No. Cycles	Avg. Load Rate (cps)	Average Remaining Slip After Load Release (In.)	Ultimate Load Capacity During Static Reloading (Kips)
1B	0-18.1	100	0.14	0	
	0-27.9	100	0.14	0	
	0-38.8	100	0.08	0	
	0-48.6	100	0.08	0.00525	
	0-52.9	100	0.08	0.01300	
					76
2B	0-27.9	100	0.22	0.00125	
	0-38.8	100	0.12	0.00350	
	0-48.6	100	0.10	0.00600	
	0-57.3	100	0.10	0.00825	
	0-68.2	100	0.06	0.01250	
					137

Table 4

SUMMARY OF CYCLIC LOAD TESTS ON ANCHORS FOR TIMBER PILES

Specimen	Load Range (Kips)	No. Cycles	Avg. Load Rate (cps)	Average Remaining Slip After Load Release (In.)	Ultimate Load Capacity During Static Reloading (Kips)
3B	0-18.1	100	0.22	0	
	0-23.5	100	0.34	0	
	0-38.8	100	0.26	0	
	0-48.6	100	0.13	0	
	0-57.3	100	0.14	0.02875	
					85
4B	0-18.8	100	0.24	0.00025	
	0-27.9	100	0.15	0.00025	
	0-38.8	100	0.12	0.00075	
	0-48.6	100	0.07	0.00100	
	0-57.3	100	0.06	0.00175	
	0-68.2	100	0.06	0.00575	
					142
5B	0-18.1	100	0.17	0	
	0-27.9	100	0.18	0.00100	
	0-38.8	100	0.15	0.00150	
	0-48.6	100	0.09	0.00200	
	0-57.3	100	0.11	0.00250	
	0-68.2	46	0.07	0.00975	
					--
6B-I	0-18.1	100	0.15	0.00050	
	0-27.9	100	0.20	0.00150	
	0-38.8	100	0.13	0.00350	
	0-48.6	25	0.06	0.04600	
					55
6B-II	0-18.1	100	0.15	0.00100	
	0-27.9	100	0.20	0.00200	
	0-38.8	100	0.13	0.00500	
	0-48.6	25	0.06	0.00800	
					55+

A detailed analysis of the structural performance of the various pile anchors is given in the Appendix. The analysis is made with respect to the consistency of results obtained from both ends of a specimen, the consistency of results obtained between specimens containing identical anchors, how well the anchor performs as compared to the control specimen, how well the anchor performs during cyclic loading, how well it recovers from cyclic loading during static reloading and how its ultimate strength compares with other anchors in its pile class.

The ultimate strength of each anchor was compared with the desired minimum ultimate capacity of 36 kips for a timber pile anchor and 56 kips for a steel pile anchor. As per California Bridge Department design procedure and the 1969 AASHO Standard Specifications for Highway Bridges, these values are the allowable uplift loads for 45 ton timber and 70 ton steel friction pile respectively calculated as 40% of the designed allowable working load. It is to be noted that the actual ultimate load capacity determined for each anchor is the actual maximum load the anchor will take and includes no factor of safety. Even after failure, however, as defined by continuous slip between the footing and pile without appreciable increase in applied load, in no case was there evidence of a complete separation between the pile and the footing as occurred when no anchor was present.

The ultimate strengths of the anchors were attained at slip values ranging from 0.004 inch to 0.10 inch with slips of from 0.05 inch to 0.10 inch predominating. It is expected that slips of this magnitude can readily be tolerated in pile anchors.

The cost of each anchor, installed, was estimated so that the anchors could be compared on the basis of cost as well as structural performance. The cost of each anchor is shown in the following table and on the pile anchor detail sheets in the Appendix:

Pile Type	Pile Anchor Type	Estimated Cost, Installed
Steel	No. 1	$ 12.00
"	" 2	4.50
Timber	" 3	29.50
"	" 4	16.50
"	" 5	6.00
"	" 6 Var I	9.50
"	" 6 Var II	6.50

Anchor type No. 2 is the least costly and easiest to install of the two anchors tested for use with steel piles. Anchor type No. 5 is the least costly and easiest to install of the four anchor types tested for use with timber piles.

DISCUSSION

Since current California bridge design practice is to base footing designs on a concrete compressive strength of 3250 psi, it was originally intended to test the specimens in Group A at a concrete compressive strength of 3000 psi. However, the strength gain was more rapid than anticipated from previous job records for the concrete mix used, and this group was tested at a compressive strength of 4110 psi at an age of 20 days. It was hoped that group C could be tested at 3000 psi, but again the strength gain was very rapid. It was felt that the specimens should not be tested at an age of less than 7 days, hence the concrete strength for this group was 3490 psi. The cyclic load specimens in group B were tested at a cylinder strength of 3920 psi.

There was only 600 psi difference among the average cylinder strengths of the three groups of specimens at the time of testing. As discussed in the Appendix, there is evidence to indicate that concrete strength probably affects the tensile load capacity of a plain steel or timber pile imbedded in concrete due to the shear strength developed, see Figure A-3, but the difference in concrete strength in this test series is small enough that the concrete can be considered the same strength for the three groups. The cylinder strengths at the time of testing as shown in Table 1, were slightly higher than the current standard design concrete cylinder strength for bridge footings of 3250 psi.

Concrete compressive strengths were determined from test cylinders fabricated from concrete sampled in accordance with Test Method No. Calif. 539. Test cylinders were molded and field cured in accordance with Test Method No. Calif. 540 using initial Field Storage Method 2 and cured and tested after receipt at the testing laboratory in accordance with Test Method No. Calif. 521.

It was also intended to test the timber pile anchors while the piles were in a saturated condition since at many times the timber piles are saturated when they must resist their maximum loads. Prior to installing the timber piles in the test specimens they were soaked in water for several days, but it was extremely difficult to keep the piles completely saturated while waiting for the concrete to gain strength since the tests were made in the middle of summer. It is therefore, doubtful that the piles were saturated at the time of testing the specimens, and the effect of moisture content on the anchor capacities is uncertain.

The possible effects of group action of pile anchors in the footings were not investigated in this project. However, the cross section of the test specimen was designed to account for the theoretical area of influence of the pile in a footing using the current minimum pile spacing of 3 feet center to center. A 3.5' square test block was actually used in the test. The extra 0.5' was included to provide for concrete cover for the footing reinforcment.

To determine possible variations in loading among the four rams and to correlate hydraulic line pressure with actual applied load, the hydraulic rams were calibrated in a compression testing machine at the Division of Highways Materials and Research laboratory. The four rams were connected with the pump and hydraulic load cell exactly as during the field testing. The calibration procedure consisted of first loading each individual ram in 100 psi increments to a load of 1000 psi hydraulic line pressure. The load was applied using the manual pump rather than loading the rams by the machine. Actual machine load was read at each 100 psi increment of hydraulic line pressure. Second, load was applied to the testing machine using all four rams simultaneously to a load of 300 psi line pressure. This corresponded to a true total applied load of 129 kips.

From the individual ram calibration data it was found that the greatest difference between any of the rams at 1000 psi line pressure was 0.2 kip with the ram approximately half extended. This corresponds to a maximum moment about the centroid of the pile cross section of 0.22 foot kips due to differences in applied loads only. Thus eccentric loading during testing was minimal.

A detailed description of the testing of each specimen and comparisons of results from the 3 groups are presented in the Appendix.

CONCLUSION

The following conclusions are subject to the restricting parameters, such as imbedment length, concrete strength etc., of this project and may have to be modified somewhat if any of these parameters are changed.

1) Positive anchoring devices are necessary with both steel and timber piles to guarantee that the full desired ultimate pullout capacity of 56 kips for steel pile anchors and 36 kips for timber pile anchors is available to provide an adequate safety factor.

2) Except for anchor type No. 6, all anchors tested consistently demonstrated ultimate capacities in excess of the desired ultimate capacity of 56 kips for steel piles and 36 kips for timber piles.

3) Both steel pile anchors tested were able to resist 100 cycles of loading between 0 and 56 kips at an average load rate of approximately 0.1 cycles per second without appreciable permanent slip. However anchor type No. 1 appeared border line. Both anchors demonstrated ultimate capacities in excess of 56 kips during static reloading.

4) All timber pile anchors tested were able to resist at least 100 cycles of loading between 0 and 36 kips at an average load rate of at least 0.1 cycles per second without appreciable permanent slip. Except for anchor type

No. 5 which was not reloaded, all anchors demonstrated ultimate capacities in excess of 36 kips during static reloading.

5) Of the two anchor types tested for use with steel piles anchor type No. 2 gave the best performance. (2 #6x4' bent bars through holes in the pile web.)

6) Of the four anchor types tested for use with timber piles anchor type No. 4 gave the best performance. (Steel plates bent into a hook shape and nailed to the pile.)

7) Anchor type No. 2 is the least costly and easiest to install of the two anchors tested for use with steel piles.

8) Anchor type No. 5 is the least costly and easiest to install of the four anchors tested for use with timber piles.

9) It may be possible to increase the capacity of the plain pile to footing connection by increasing the imbedment length of the pile into the footing. This becomes a matter of practicability however due to conflicts with the column and footing reinforcement.

10) As previously discussed, anchor type Nos. 1, 2, 3, 4 and 5 all increase the pullout capacity of the pile to footing connection beyond that available with plain piles. In selecting an appropriate pile anchor to be used, four factors must be considered:

(1) The amount of slip that can be tolerated between the pile and the footing must be estimated so that the ultimate capacity at this slip can be determined from the load vs slip figures.

(2) The factor of safety to be applied to the anchor's ultimate capacity must be determined and the allowable anchor load calculated.

(3) The allowable anchor load must be compared with the anticipated pile uplift working load.

(4) The costs of the suitable anchor devices must be compared to make the final anchor selection.

RECOMMENDATIONS

1) Use anchors with all steel and timber piles to provide a positive connection between the pile and footing.

2) Use pile anchor type No. 2 with steel piles.

3) Use pile anchor type No. 5 with timber piles.

4) Use pile anchor type Nos. 3 or 4 with timber piles when pile anchor ultimate uplift capacities in excess of 36 kips are desired.

IMPLEMENTATION

Anchor type Nos. 1, 2, 3 and 5 have already been used in California Highway Structures. Each of these anchors has a capacity at least equal to its respective allowable design capacity of 56 kips for a steel pile anchor and 36 kips for a timber pile anchor.

The Bridge Departments's Pile Committee is currently reviewing the findings of this study. It is expected that they will recommend that in future construction of California highway structures anchors be used on all steel and timber piles. It is anticipated that a slightly modified version of anchor type No. 2 will be used with steel piles. Rather than 2 #6 bars at a 45 degree angle, the modified anchor will probably consist of 2 #8 bars at a 60 degree angle. It is anticipated that anchor type No. 5 consisting of 4 #6 hook bars and 2 #4 hoops will be used with timber piles.

APPENDIX

Control Specimens

Two control specimens, 7C for the steel pile and 8C for the timber pile, were tested statically to determine the tensile load characteristics of the pile to footing connection when no pile anchor is provided. The results of these tests are shown graphically in Figure A-1 for the steel pile and in Figure A-2 for the timber pile. The loads at various slips along with the ultimate capacities are shown in Table 2 for purposes of comparison with the results from the anchor devices.

The results from the two ends of the steel pile control specimen were very consistent up to the ultimate tensile load capacity, which was surprisingly high. Since the capacity of the control specimen was 60 kips, it appears that under certain conditions a steel pile imbedded in a concrete footing, with no anchor device, is capable of withstanding a static tensile load equal to the desired minimum ultimate capacity for 70 ton steel piles of 56 kips. However the 60 kip capacity performance is probably high since it is the result of only one test in which the conditions were controlled and in which the concrete strength of the specimen was higher than the normal design strength. In addition, failure can be relatively sudden at loads near ultimate as shown by the well defined yield point in Figure A-1.

Applied Load vs. Slip Data
for Specimen 7C - Static Loading
(Steel Pile Control Specimen)

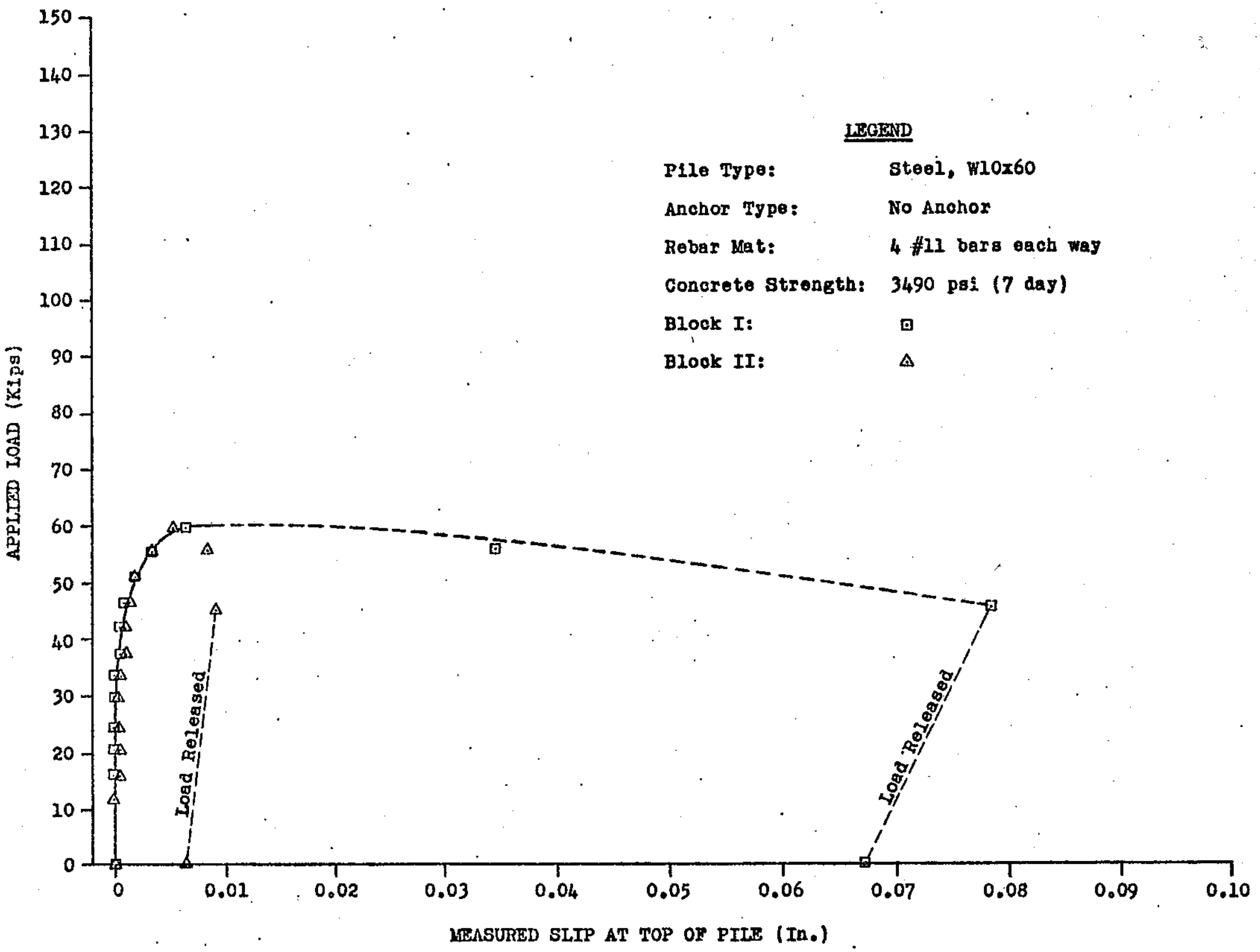


Figure A-1

Applied Load vs. Slip Data
for Specimen 8C - Static Loading
(Timber Pile Control Specimen)

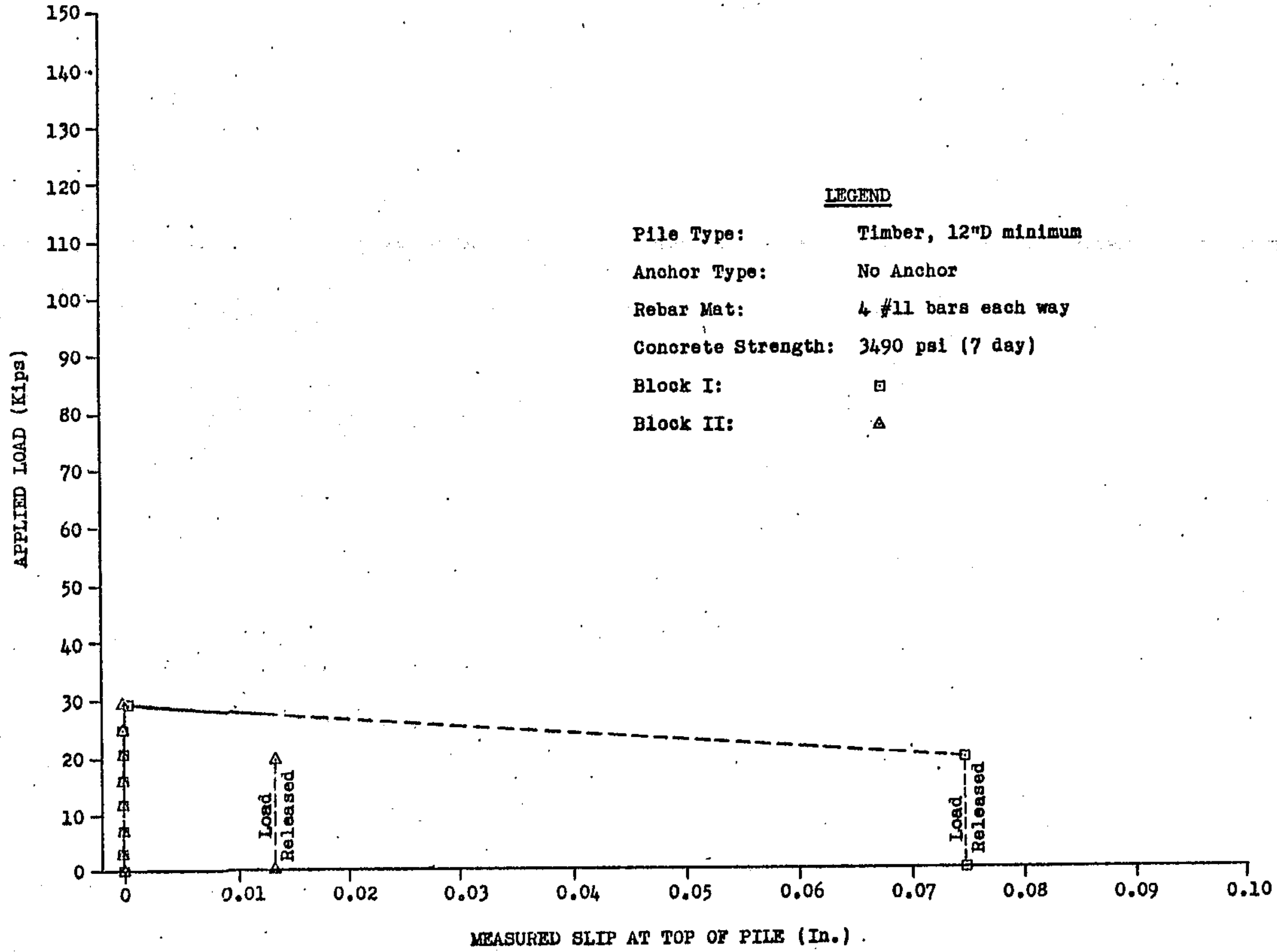


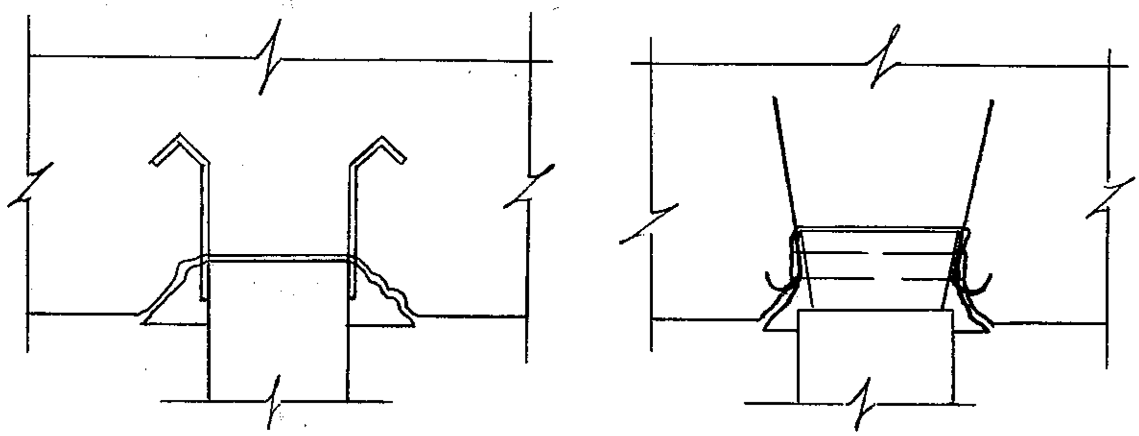
Figure A-2

The results obtained from the two ends of Specimen 8C, the timber pile control specimen, were as consistent as those of Specimen 7C as shown in Figure A-2. The capacity of this pile to footing connection was 29 kips. This capacity is well below the desired minimum ultimate capacity of 36 kips for timber piles.

It is not certain what caused the large difference in capacity between the steel and timber control specimens, but there seem to be several possibilities. They are: 1) the shape of the two piles, 2) difference in bond characteristics of the two materials, and 3) slightly different imbedment lengths for the two pile types.

As in the case of the steel pile control specimen, failure of the timber pile to footing connection with no anchor can be sudden as shown by the test results for the blocks in Figure A-2. Obviously, then, some type of positive connection between a timber pile and concrete footing is necessary if an uplift capacity of the magnitude of 36 kips is desired.

The capacity of this simple connection is almost certainly related to the length of imbedment of the pile into the footing and concrete strength although these variables could not specifically be tested in this project. An examination of the specimens revealed a mode of failure as shown in Figure A-3.



Typical

Anchor Type No. 5

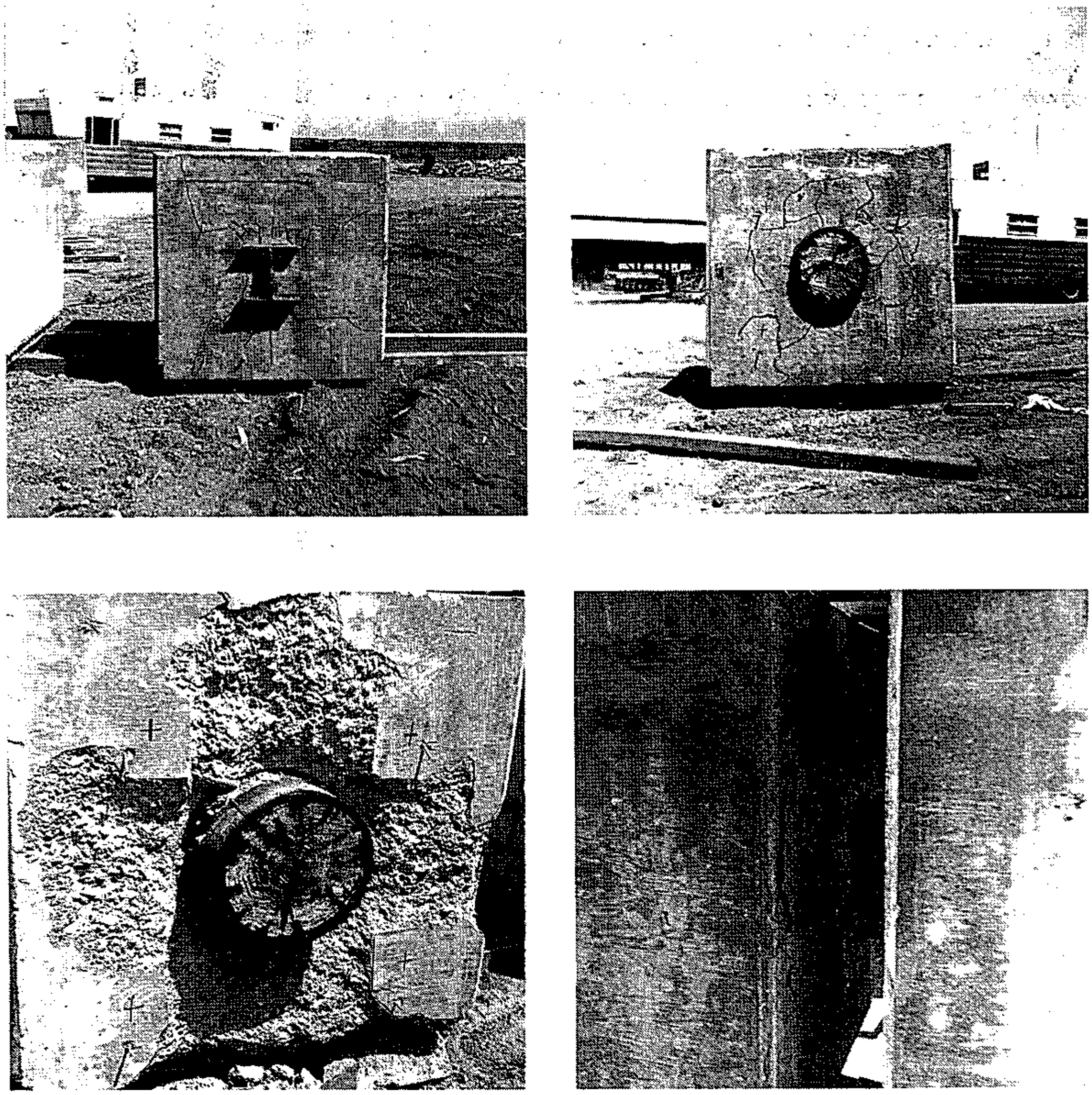
Mode of Concrete Footing Failures

Figure A-3

The concrete failure is similar to reinforcing steel pullout type failure which is known to be influenced by imbedment length and concrete strength. The size and amount of reinforcing steel probably has no effect on the plain pile's capacity to resist pulling out of the footing as long as the reinforcing steel mat is above the top of the pile.

This type of failure was also typical for each anchor tested except anchor No. 5. Photographs of several pile anchor specimens that were loaded to failure are shown in Figure A-4.

The failure mode of anchor type No. 5 was similar, but the line of concrete failure followed the #4 hoops nearly to the loaded face of the block rather than a 45 degree line from the end of the pile. See Figure A-3.



Typical Cracking Patterns in
Loaded End of Test Specimens
(Cracks Have Been Marked with
a Marking Pen for Clarity)

Figure A-4

Anchors for Steel Piles

Anchor Type No. 1

Pile Anchor Type No. 1 consists of 2 3"x1/2"x2'-0" steel plates bolted to the web of the pile with a single high strength bolt in a friction type connection. Details of this anchor are shown in Figure A-5.

The results from the three test specimens containing this anchor are presented graphically in Figures A-6 and A-7 for the static load tests and in Figure A-8 for the cyclic load tests. The loads at various selected slip values for the static tests are tabulated in Table 2, and a numerical summary of the cyclic load data is shown in Table 3.

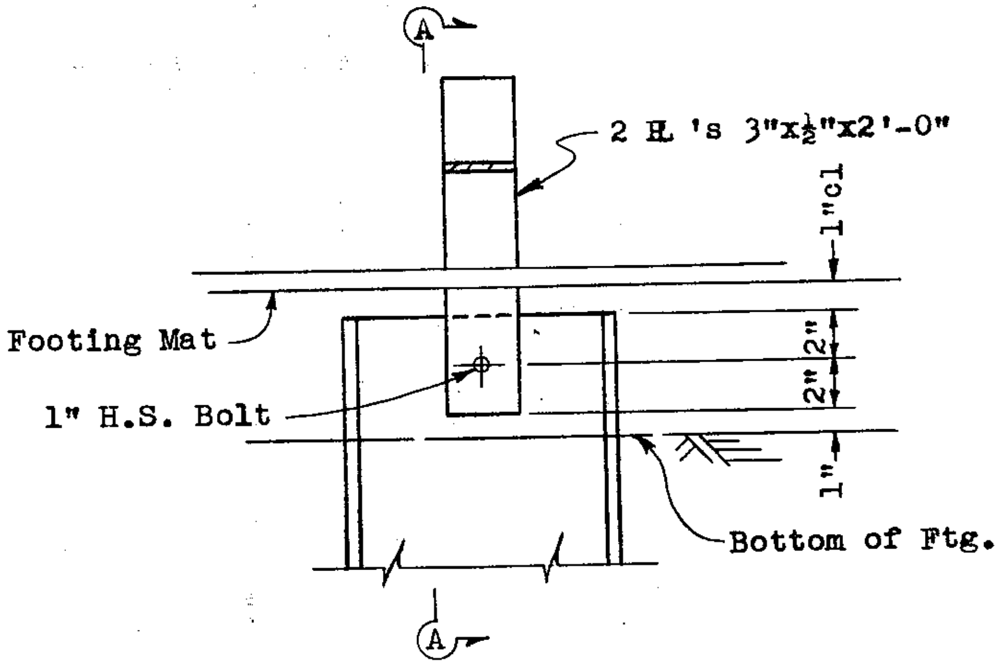
The ultimate load capacities of Specimens 1A and 1C were 62 and 91 kips respectively as compared to 60 kips for the control specimen. The large difference between the capacities of the two specimens containing anchors is not due to differences in concrete strength or amount of reinforcing steel since the specimen with the lowest capacity had the highest concrete strength and greatest amount of steel. The difference is apparently the variation to be expected with this anchor.

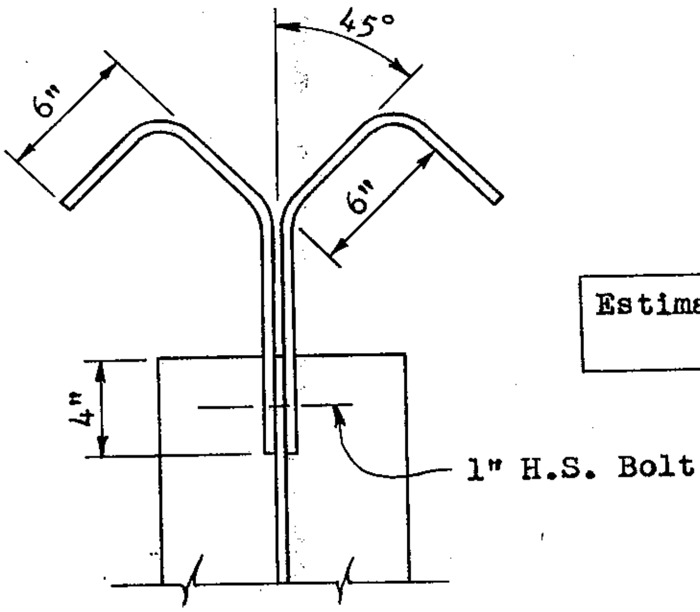
Specimens 1A, 1C and the control Specimen 7C are compared in Figure A-9. Up to an applied load of 46 kips the behavior of Specimens 1A and 1C were nearly identical to that of the control specimen. Beyond this point none of the three behaved the same way. The behavior of Specimen 1A and the control specimen remained somewhat the same up to a slip of 0.06 inch, at which point one end of the control specimen began to fail rather suddenly. Both ends of Specimen 1A continued yielding to a slip of 0.10 inch with little decrease in its ability to sustain the load. Specimen 1C continued to yield gradually at increasing loads to its capacity of 91 kips and then continued to maintain this load while yielding to a slip of 0.10 inch.

From the test results it is apparent that anchor type No. 1 does not consistently resist much more load than a plain steel pile imbedded in concrete even though it was demonstrated that the anchor is capable of resisting loads up to 50% greater than the plain pile. The main advantage of using this anchor is the reduced chance of sudden failures of the pile to footing connection at tensile loads near the anticipated 56 kip desired capacity.

The capacity of anchor type No. 1 with respect to the 56 kip desired minimum ultimate capacity appears to be borderline during cyclic loading although recovery after cyclic loading to near failure was good as shown in Figure A-8. No permanent slip occurred at the end of the pile until 50 cycles into the 0 to 48.6 kip load range. Cyclic loading was discontinued after the 0 to 52.9 kip range had been applied because failure of the specimen appeared imminent.

Although the ability of anchor type No. 1 to resist 100 cycles of loading between 0 and 56 kips without a large amount of slip is questionable, this anchor has an adequate ability to recover from incipient cyclic loading failure. Following cyclic loading Specimen 1B was unloaded completely and then reloaded to failure statically to determine its recovery capabilities as shown by the second portion of the curve in Figure A-8. The final capacity during this loading was estimated to be 76 kips which is slightly higher than that expected for purely static loading. As with Specimens 1A and 1C, failure in this case was not sudden; the anchor appeared capable of sustaining loads near ultimate capacity while yielding.



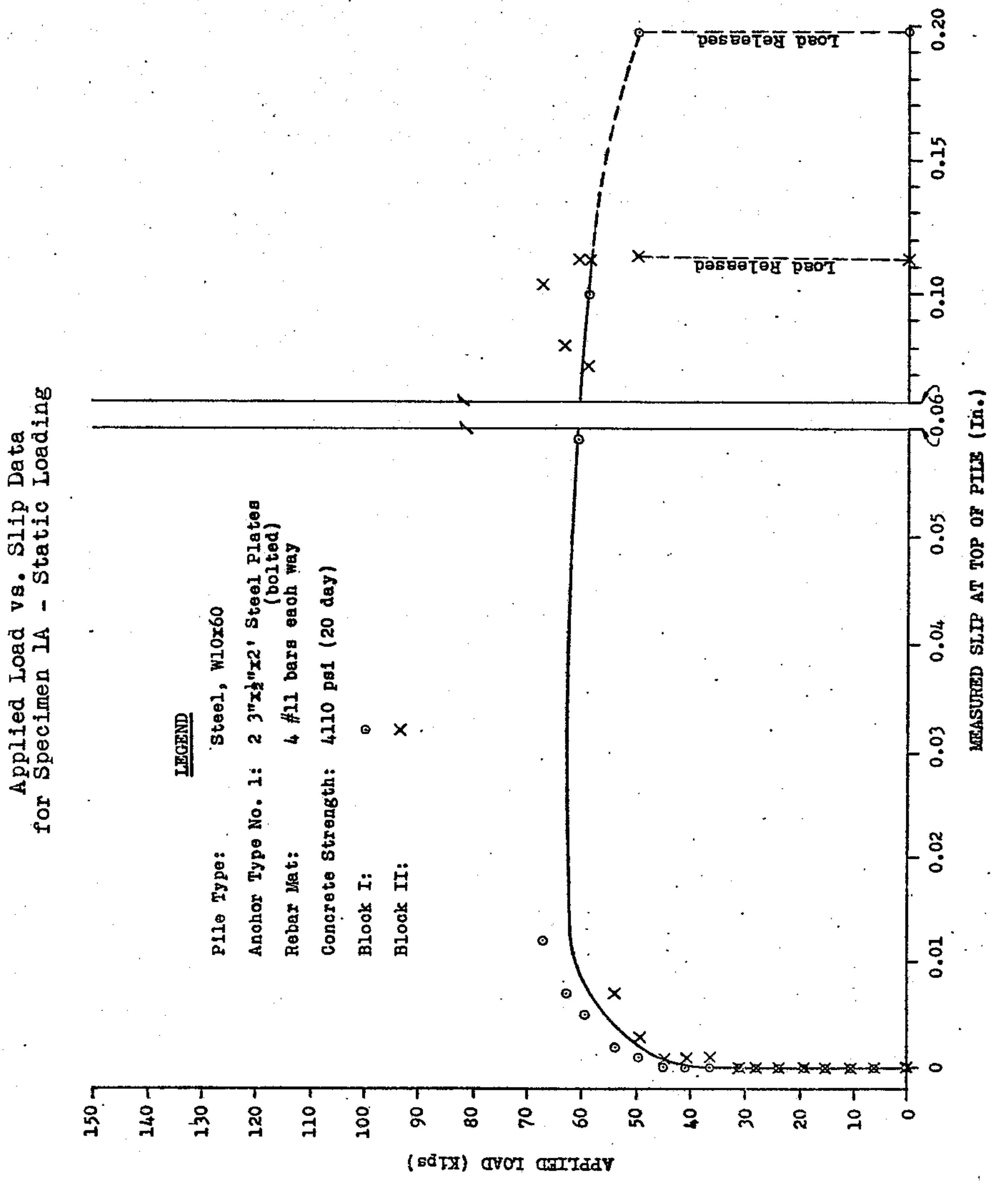


Section A-A

Estimated Cost, Installed:
$12.00

DETAILS FOR
PILE ANCHOR TYPE NO. 1

Figure A-5



Applied Load vs. Slip Data
for Specimen 1A - Static Loading
LEGEND
Pile Type: Steel, W10x60
Anchor Type No. 1: 2 3"x½"x2' Steel Plates (bolted)
Rebar Mat: 4 #11 bars each way
Concrete Strength: 4110 psi (20 day)
Block I:
Block II:
Load Released
Load Released
APPLIED LOAD (Kips)
MEASURED SLIP AT TOP OF PILE (In.)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.10
0.15
0.20

Figure A-6

Applied Load vs. Slip Data
for Specimen 1C - Static Loading

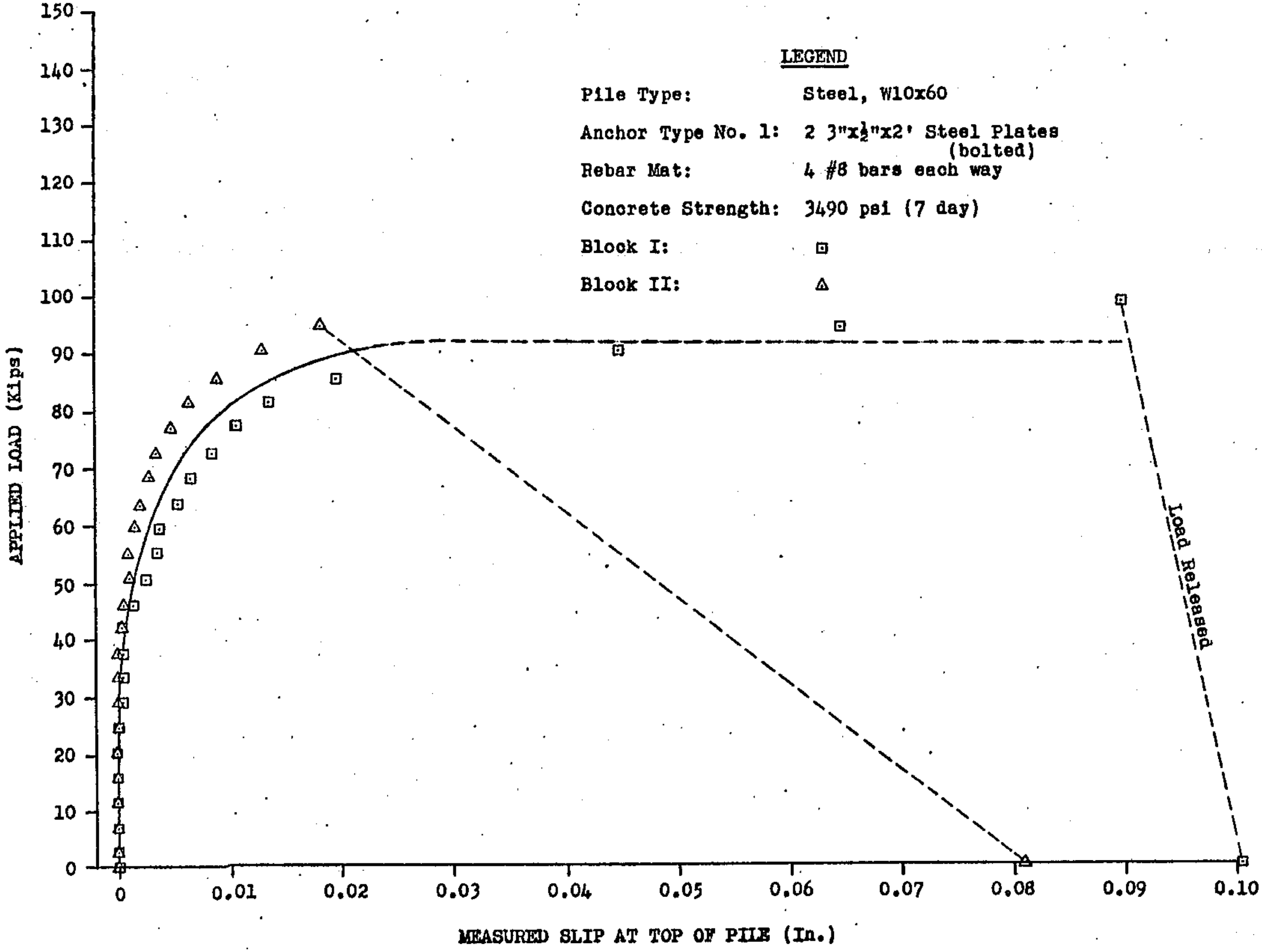


Figure A-7

Applied Load vs. Slip Data
for Specimen 1B - Cyclic Loading

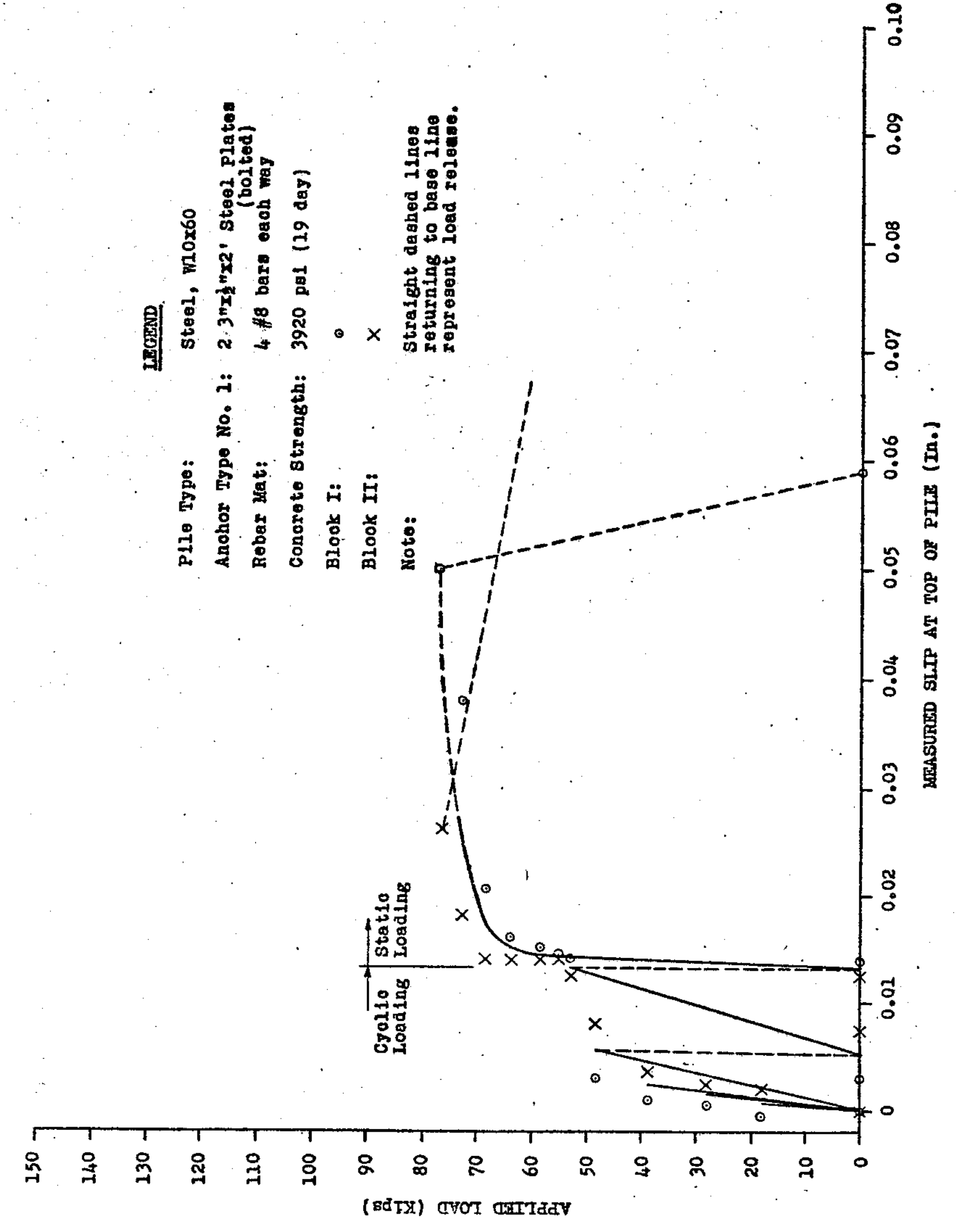


Figure A-8

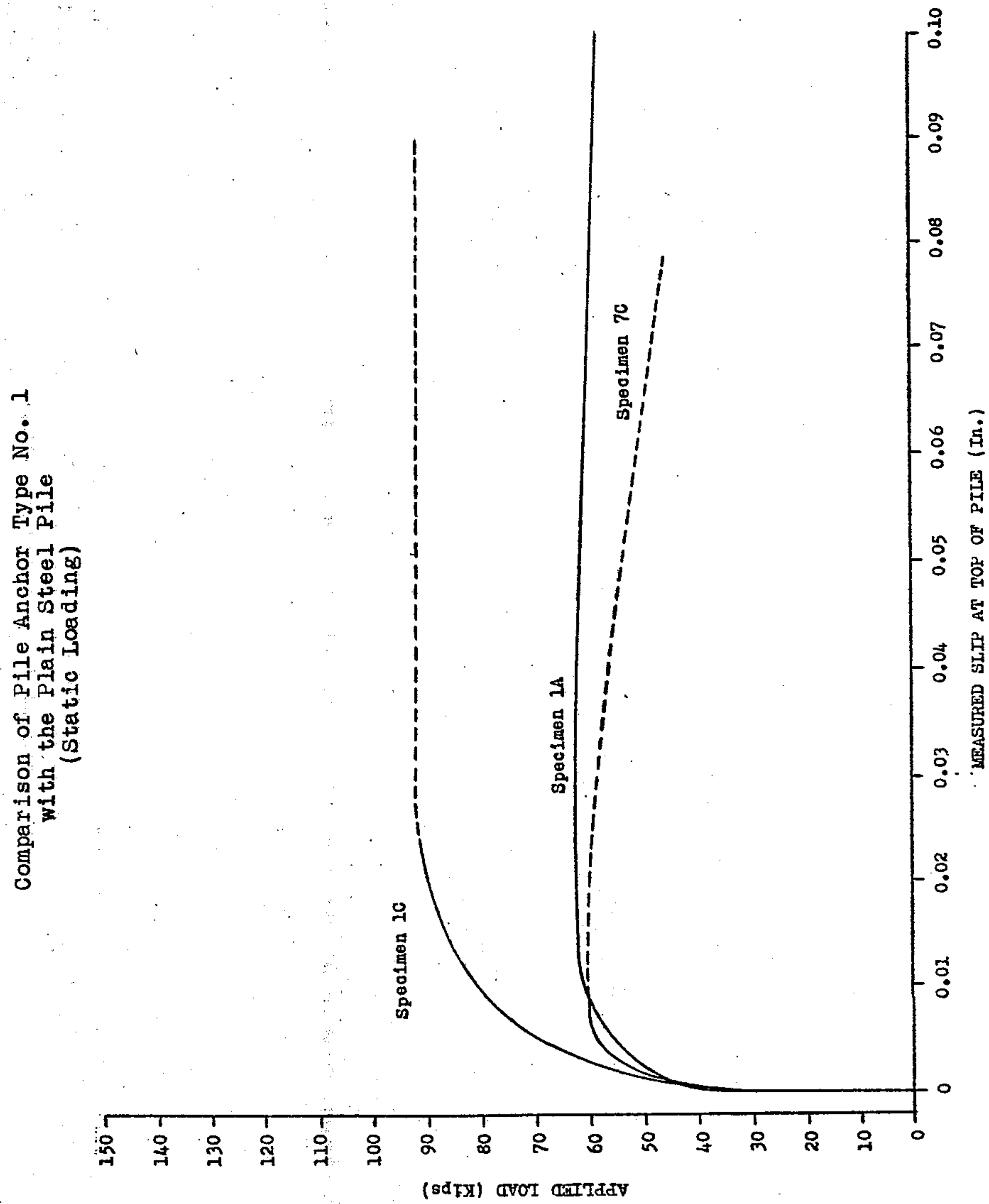

Comparison of Pile Anchor Type No. 1
with the Plain Steel Pile
(Static Loading)
Specimen 1C
Specimen 1A
Specimen 7C
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
APPLIED LOAD (Kips)
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10
MEASURED SLIP AT TOP OF PILE (In.)

Figure A-9

Anchor Type No. 2

Pile anchor type No. 2 consists of 2 #6 45° 2'-0" x4'-0" concrete reinforcing steel bars inserted through two flame cut hoes in the pile web. Figure A-10 shows the details for this anchor.

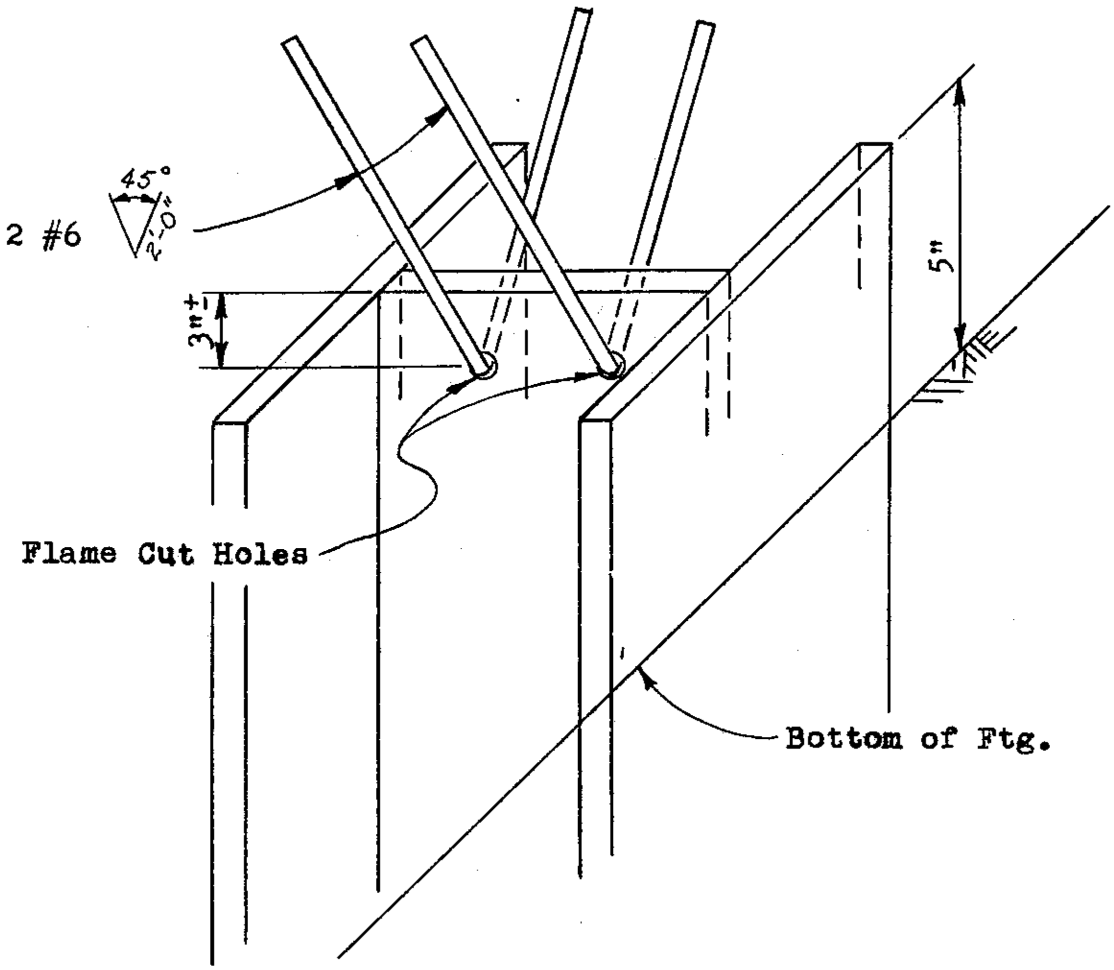
The data from both the static and cyclic load tests are shown in Figures A-11, A-12 and A-13. Loads at various selected slip values are shown in Table 2, and a numerical summary of the cyclic load tests is given in Table 3.

As shown in Figure A-14 the results from the static load tests on Specimens 2A and 2C are nearly identical up to an applied load of 116 kips. The ultimate capacities of Specimens 2A and 2C were at least 134 kips and 116 kips respectively. Specimen 2C probably would also have sustained a load of 134 kips if loading had not been terminated. Loading was terminated for both specimens prior to complete failure because of the magnitude of the load with respect to the 56 kip desired minimum ultimate capacity, and for this reason even the 134 kips ultimate strength value is probably conservative.

Up to an applied load of 56 kips there was no difference between Specimens 7C (control), 2A and 2C. Beyond this load Specimens 2A and 2C performed considerably better than the control, with anchor type No. 2 nearly doubling the ultimate tensile load capacity of the pile to footing connection for static loads.

Anchor type No. 2 performed very well during cyclic loading as shown in Figure A-13. Although a small permanent slip remained after 100 cycles of the first load range of 0 to 27.9 kips, this increased to only 0.012 inch by the end of 100 cycles of the last load range of 0 to 68.2 kips. This slip value is nearly identical to that retained by anchor No. 1 after final cyclic loading of only 0 to 52.9 kips. At the end of the final 100 cycles of loading, anchor No. 2 still did not appear to be on the verge of failure. These results indicate that anchor Type No. 2 is easily capable of withstanding at least 100 cycles of loading between 0 and 56 kips, the desired minimum ultimate capacity.

Anchor type No. 2 has an excellent ability to recover from cyclic loading. As with Specimen 1B, Specimen 2B was loaded statically after cyclic loading was completed; the ultimate strength obtained was at least 137 kips as shown in Tables 2 and 3 and Figure A-13. Although the data from the two ends of the specimen began to diverge at a load of approximately 80 kips, the maximum measured slip at the top of the pile after all testing was completed was only at most 0.05 inch.



Estimated Cost, Installed:
$4.50

DETAILS FOR
PILE ANCHOR TYPE NO. 2

Figure A-10

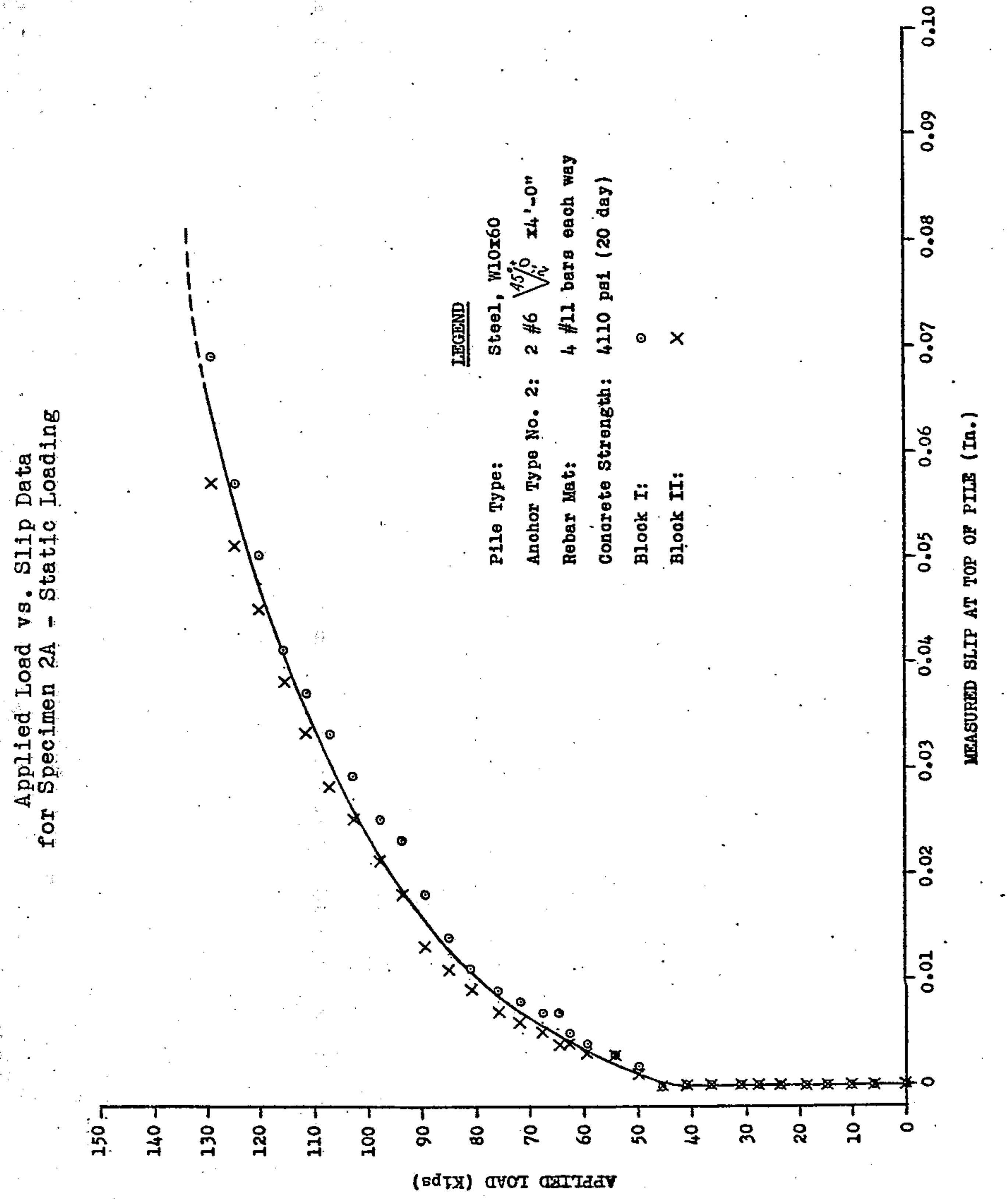
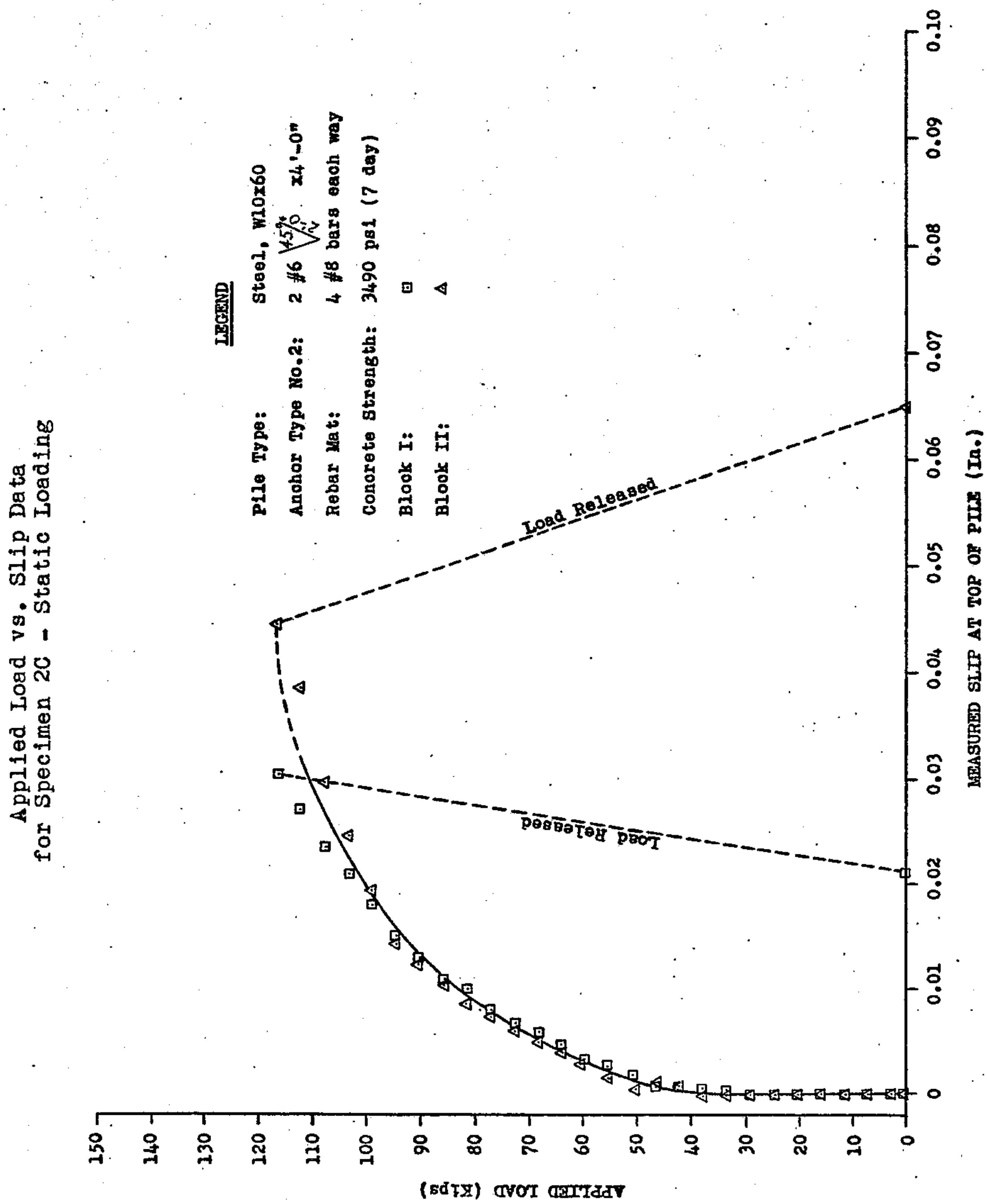

Applied Load vs. Slip Data
for Specimen 2A - Static Loading
LEGEND
Pile Type: Steel, W10x60
Anchor Type No. 2: 2 #6 x4'-0"
Rebar Mat: 4 #11 bars each way
Concrete Strength: 4110 psi (20 day)
Block I: ⊙
Block II: X
APPLIED LOAD (Kips)
MEASURED SLIP AT TOP OF PILE (In.)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

Figure A-11



Applied Load vs. Slip Data
for Specimen 2C - Static Loading
LEGEND
Pile Type: Steel, W10x60
Anchor Type No.2: 2 #6 x4'-0"
Rebar Mat: 4 #8 bars each way
Concrete Strength: 3490 psi (7 day)
Block I:
Block II:
Load Released
Load Released
APPLIED LOAD (Kips)
MEASURED SLIP AT TOP OF PILE (In.)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

Figure A-12

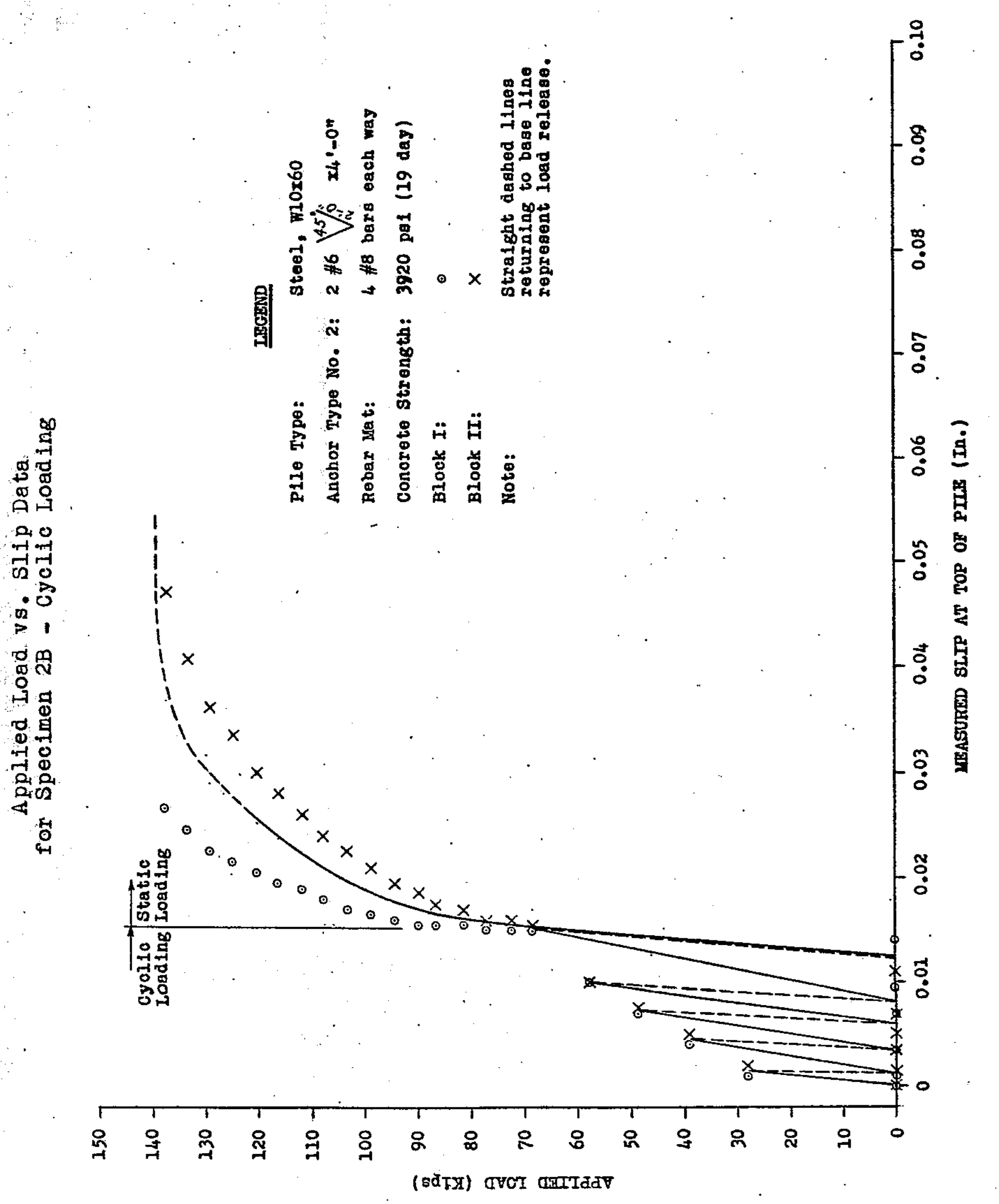

Applied Load vs. Slip Data
for Specimen 2B - Cyclic Loading
LEGEND
Pile Type: Steel, W10x60
Anchor Type No. 2: 2 #6 x4'-0"
Rebar Mat: 4 #8 bars each way
Concrete Strength: 3920 psi (19 day)
Block I:
Block II:
Note: Straight dashed lines returning to base line represent load release.
Cyclic Loading
Static Loading
APPLIED LOAD (Kips)
MEASURED SLIP AT TOP OF PILE (In.)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

Figure A-13

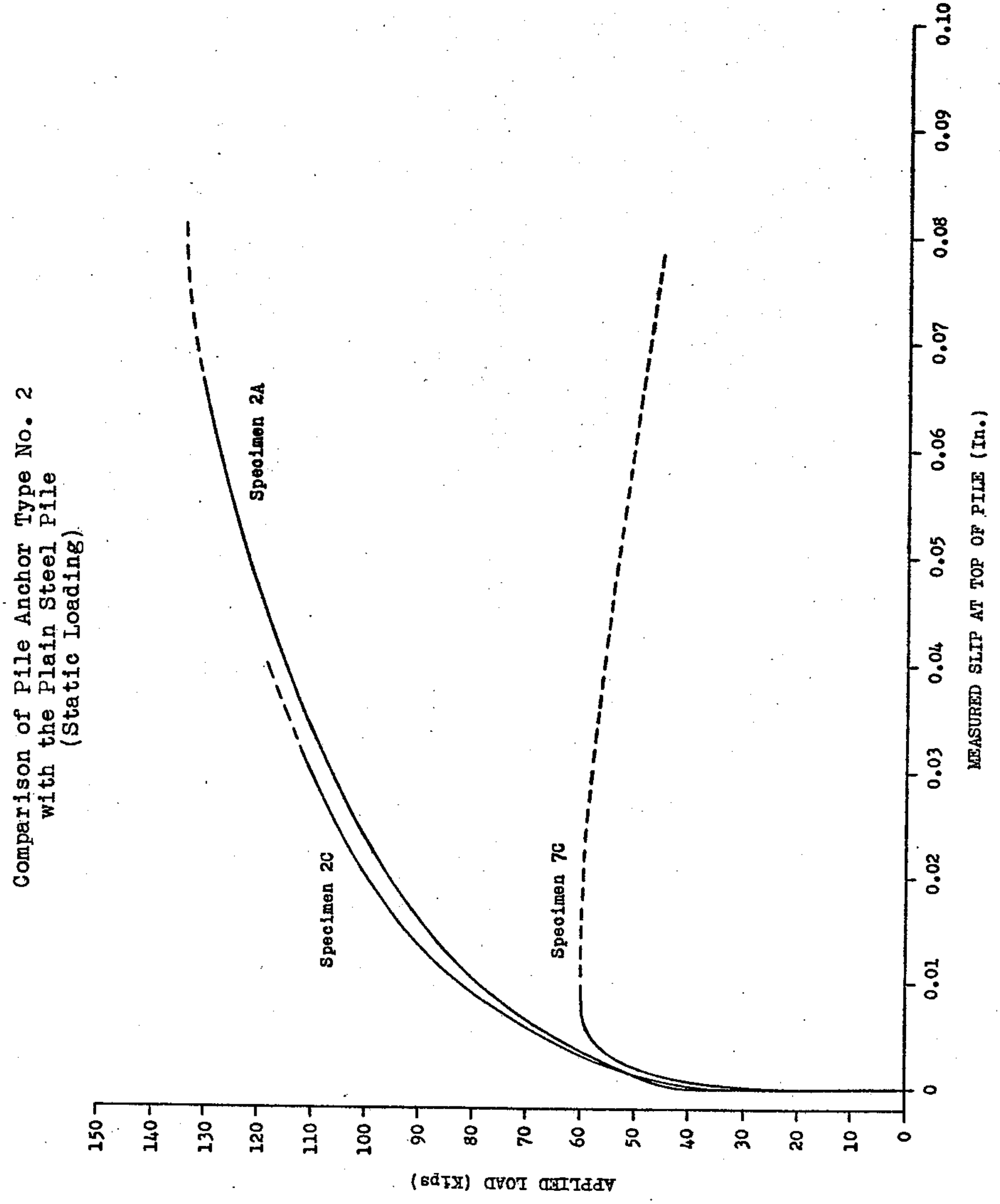

Comparison of Pile Anchor Type No. 2
with the Plain Steel Pile
(Static Loading)
Specimen 2A
Specimen 2C
Specimen 7C
APPLIED LOAD (Kips)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
MEASURED SLIP AT TOP OF PILE (In.)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

Figure A-14

ANCHORS FOR TIMBER PILES

Anchor Type No. 3

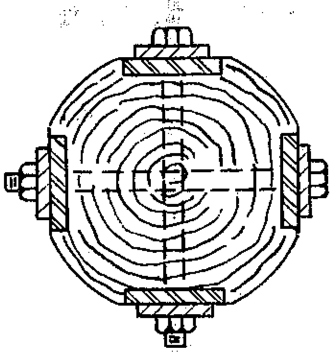
Pile anchor type No. 3 consists of 4 3"x1/2"x2'-0" steel plates bolted to the end of the pile as shown in Figure A-15.

The results of the individual load tests on the three test specimens containing this anchor are shown graphically in Figures A-16, A-17 and A-18. The results from the two ends of each specimen were very consistent as can be seen in the three figures.

Figure A-19 shows the static load vs. average slip curves for the two ends of Specimens 3A and 3C, and the curve for the Control Specimen 8C. The results from the two specimens containing the anchor are very similar; both have an estimated ultimate capacity of 69 kips. This is nearly twice the desired minimum ultimate capacity of 36 kips for timber piles and much more than twice the 29 kip capacity of the plain timber pile control specimen. The only major differences between the results from Specimens 3A and 3C were that the initial yielding of Specimen 3A was more gradual than that of Specimen 3C, and the ultimate strength of Specimen 3C was attained at an average measured slip value of 0.05 inch, about half that of Specimen 3A. The difference between the two curves was only 5 kips at the 0.05 inch slip value, however. As with both of the steel pile anchors, anchor type No. 3 is able to withstand loads near ultimate without the relatively sudden failure evident with the plain pile control specimen. See the data for Block I of the control specimen in Figure A-2.

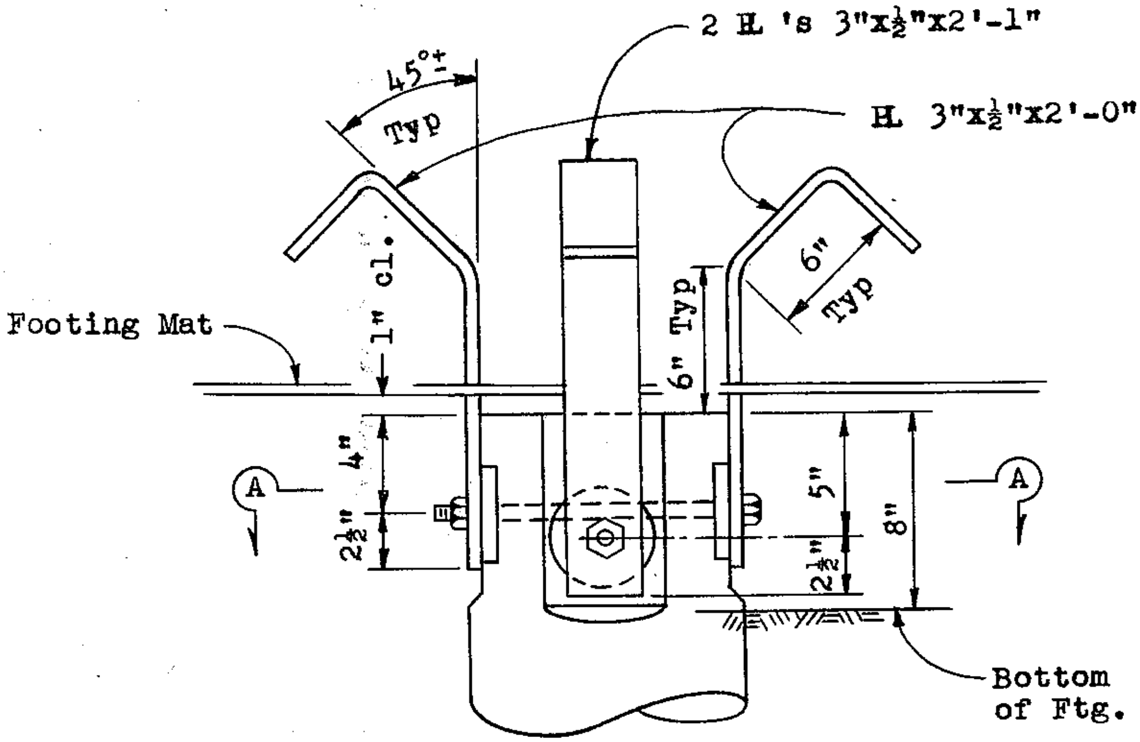
Anchor type No. 3 demonstrated adequate ability to withstand cyclic loadings with respect to the 36 kip allowable, as shown in the first part of Figure A-18. No permanent slip occurred in Specimen 3B until after 25 cycles of the 0-57.3 kips load range had been applied. See Table 4. It is evident from the Table and from Figure A-18 that within the boundaries of this test, this anchor can very readily take at least 100 slow loading cycles of 0 to 36 kips.

This anchor shows an adequate ability to recover from cyclic loading as shown in the static loading portion of Figure A-18. After loading Specimen 3B cyclically to what appeared to be impending failure at 57.3 kips, successively increasing static loads up to 85 kips were applied without complete failure of the pile to footing connection. However, the average measured slip at this load value was relatively large (0.15 inch). The application of the cyclic loads seemed to have improved the ultimate static load capacity of the anchor by approximately 25%, but at the expense of greater slip.



Section A-A

Estimated Cost, Installed:
$29.50



DETAILS FOR
PILE ANCHOR TYPE NO. 3

Figure A-15

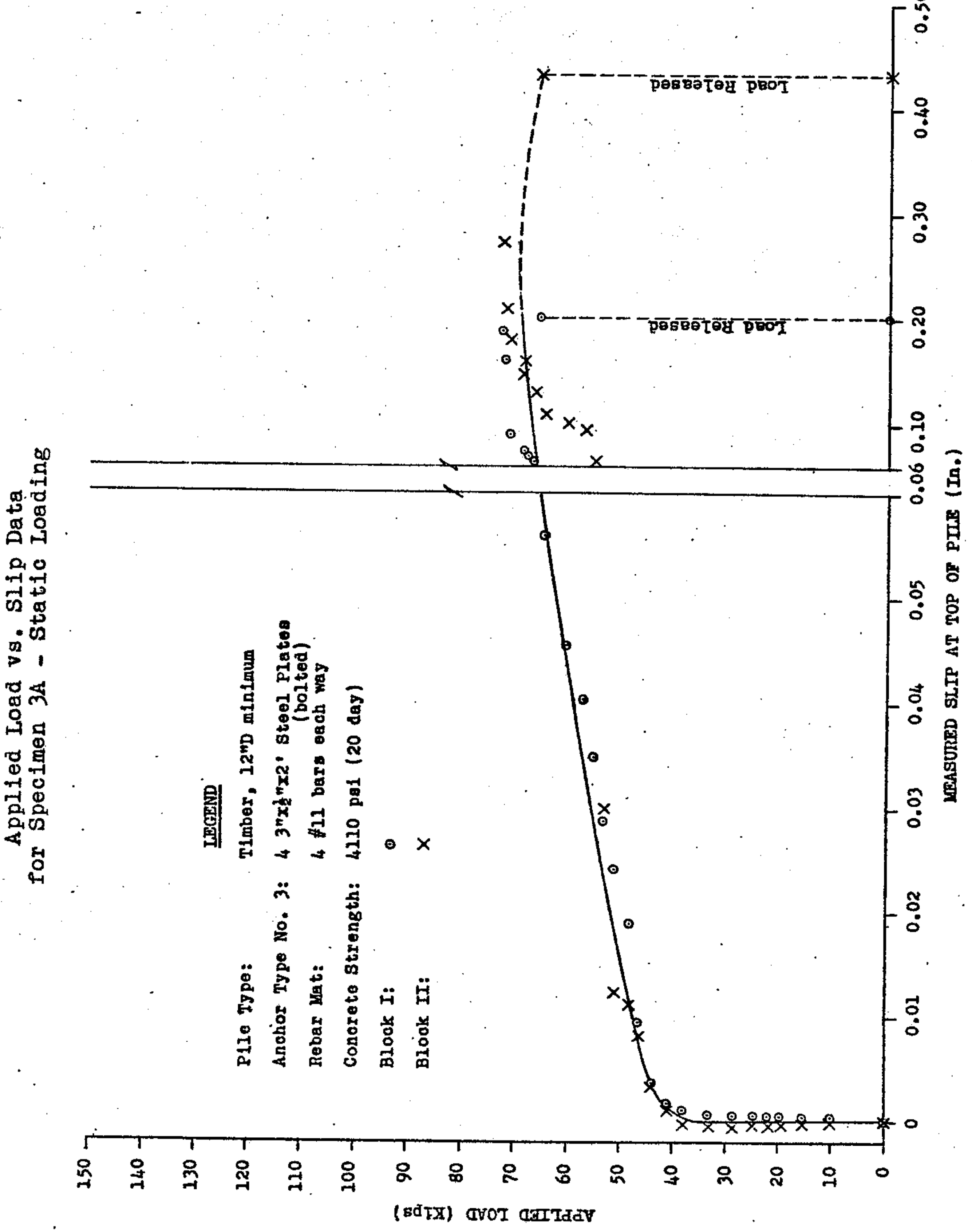

Applied Load vs. Slip Data
for Specimen 3A - Static Loading
LEGEND
Pile Type: Timber, 12"D minimum
Anchor Type No. 3: 4 3"x½"x2' Steel Plates (bolted)
Rebar Mat: 4 #11 bars each way
Concrete Strength: 4110 psi (20 day)
Block I: ⊙
Block II: X
Load Released
Load Released
APPLIED LOAD (Kips)
MEASURED SLIP AT TOP OF PILE (In.)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
0.01
0.02
0.03
0.04
0.05
0.06
0.06
0.10
0.20
0.30
0.40
0.50

Figure A-16

Applied Load vs. Slip Data
for Specimen 3C - Static Loading

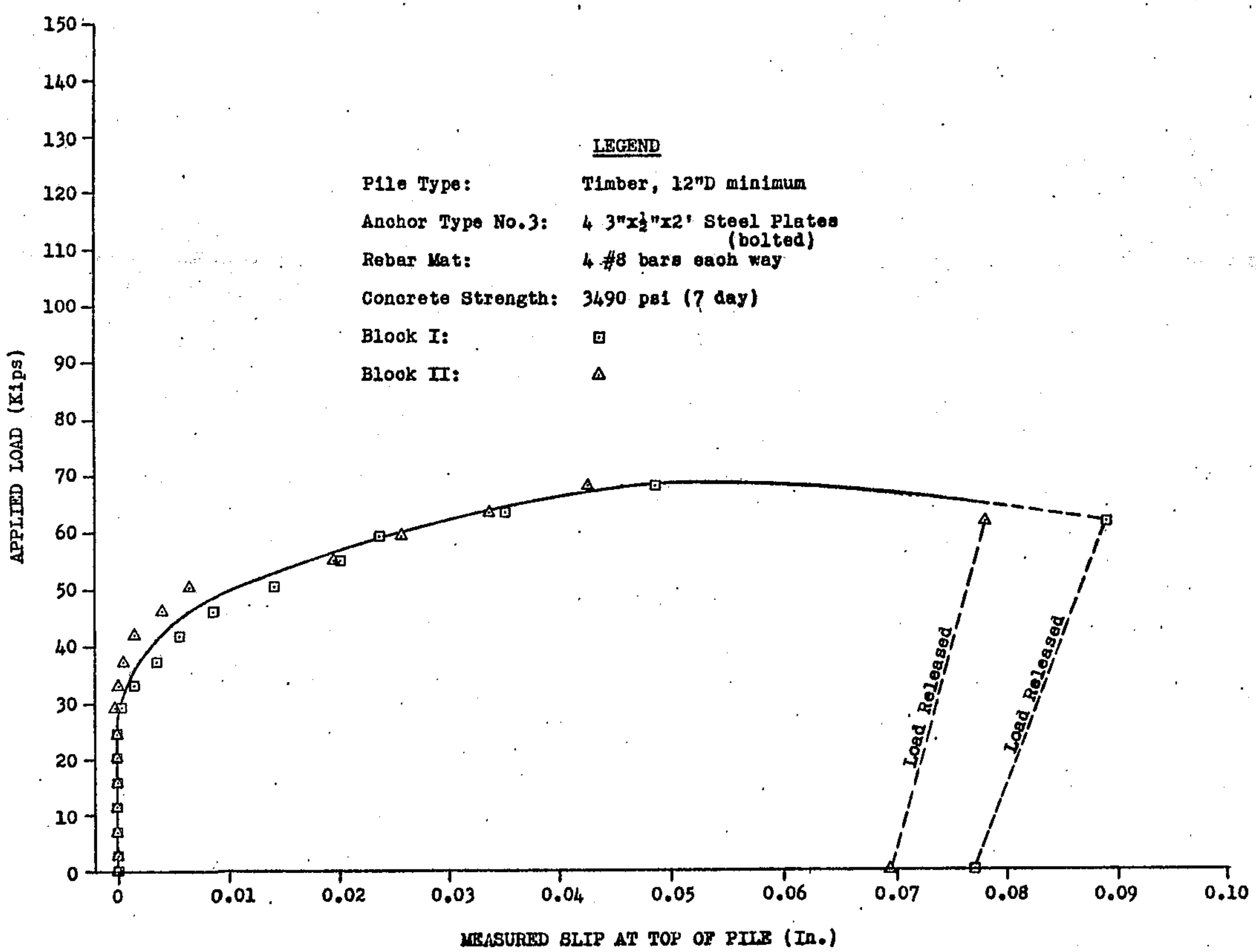


Figure A-17

Applied Load vs. Slip Data
for Specimen 3B - Cyclic Loading

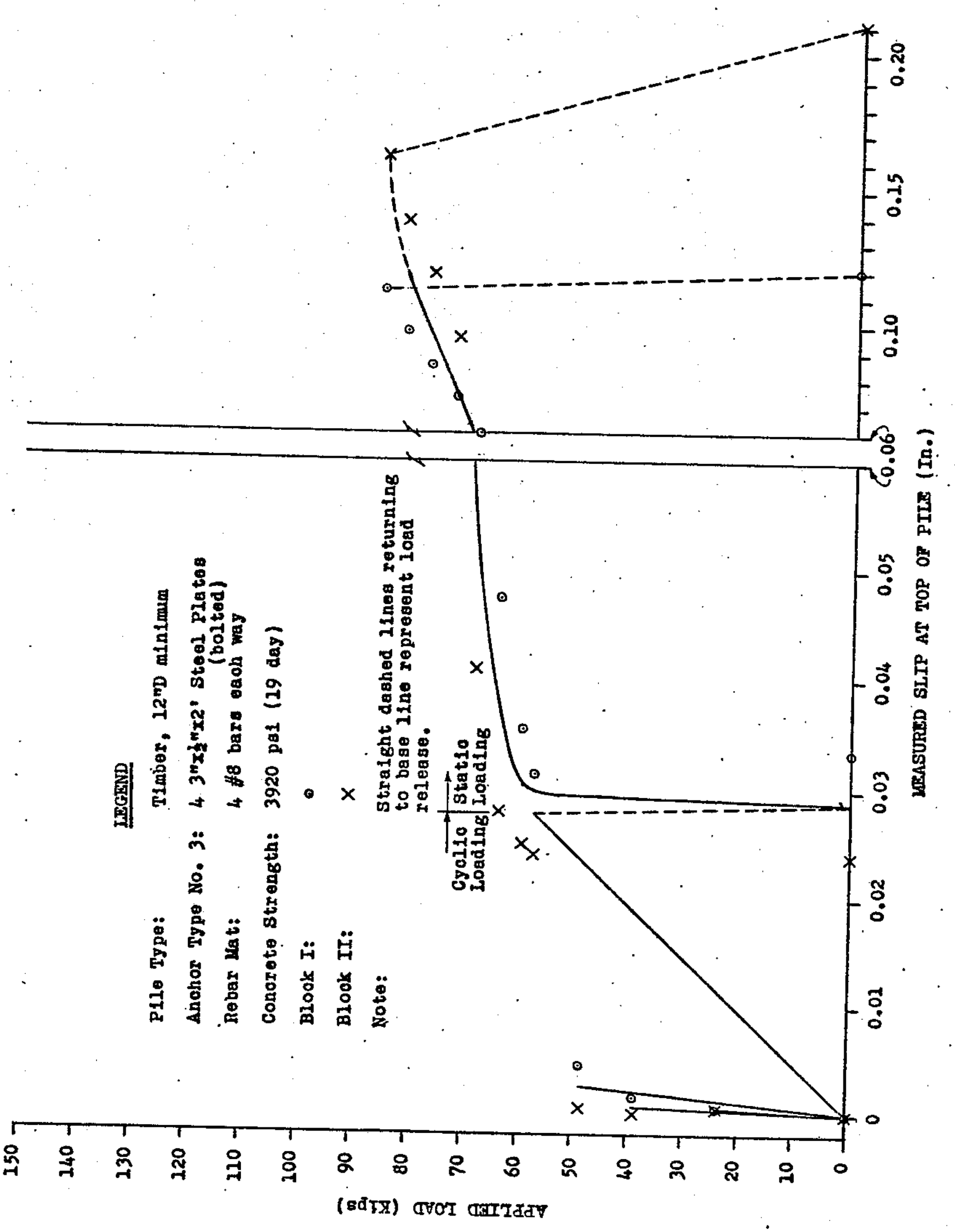


Figure A-18

Comparison of Pile Anchor Type No. 3
with the Plain Timber Pile
(Static Loading)

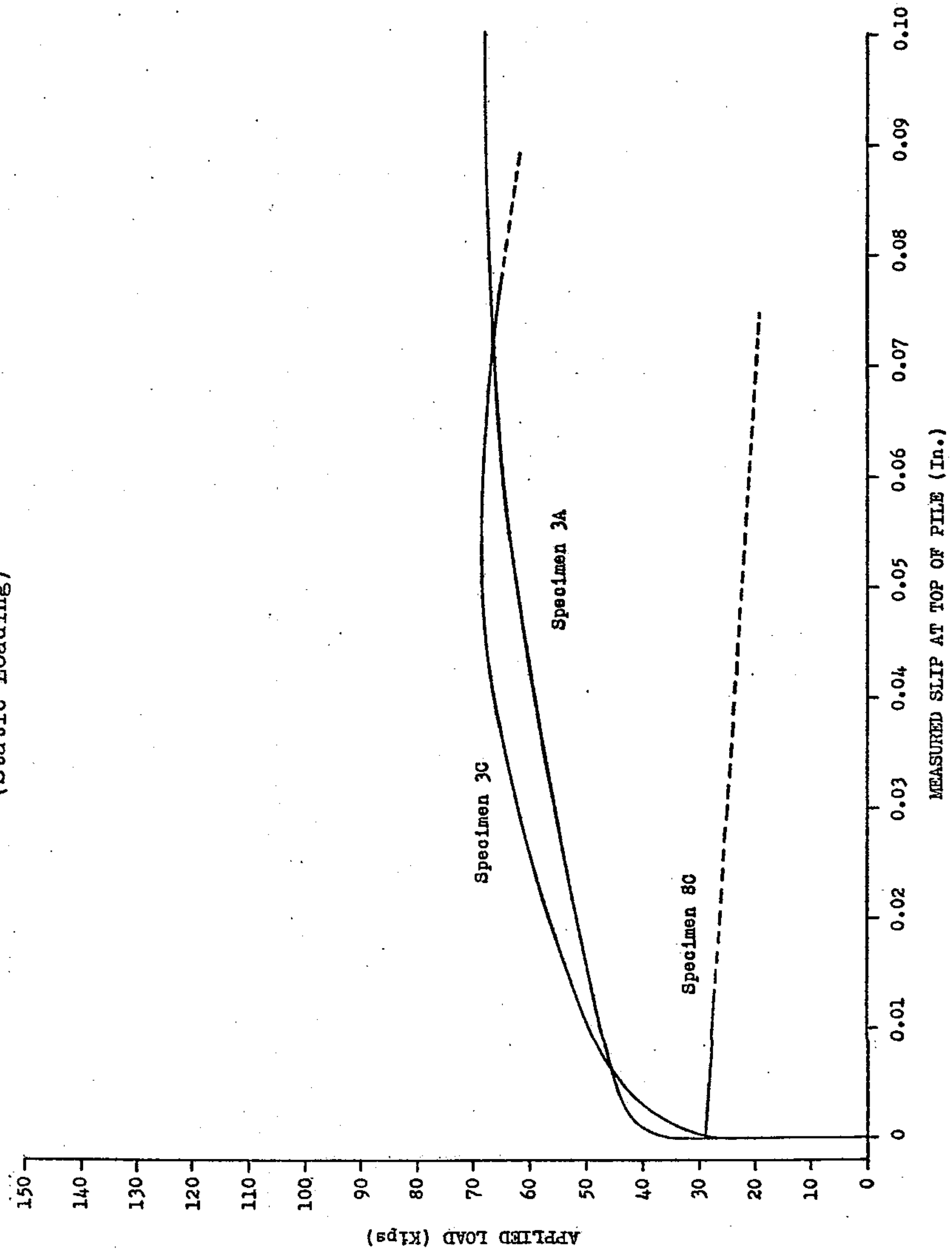


Figure A-19

Anchor Type No. 4

Anchor type No. 4 consists of 4 3"x1/2"x2"-0" steel plates, each fastened to the end of pile by 33 hardened rectangular nails driven through prepunched holes in each plate. Details for this anchor are shown in Figure A-20.

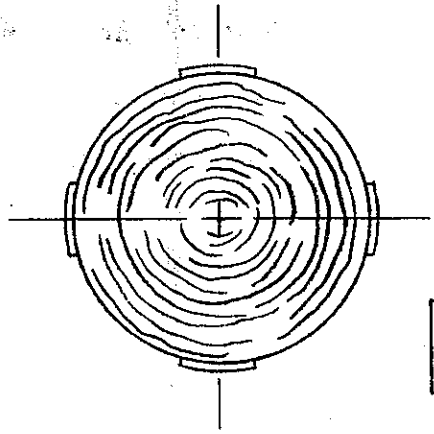
The results of the individual load tests on the three test specimens containing anchor type No. 4 are shown in Figures A-21, A-22 and A-23. Although the results agree quite closely between the two ends of each specimen, there was a large difference in the ultimate static load capacities of Specimens 4A and 4C. The ultimate capacities were 151+ kips and 120 kips for Specimens 4A and 4C respectively.

Figure A-24 is a comparison of the static loading test results from Specimens 4A and 4C and the timber pile control Specimen 8C. From this figure it is apparent that the difference between the two specimens is due primarily to the difference in yield points since the two curves are essentially parallel beyond a measured slip of approximately 0.001 inch. In this case the specimen with the higher load capacity also had the highest concrete strength and greatest amount of reinforcing steel, but it is doubtful that this is the reason for the different capacities since this result was not evident in four of the other five anchors tested. It is more likely that the variation was due to the nailed connection of the anchor to the timber pile.

Even though the difference in capacities of the two specimens was 31 kips, both anchors far exceeded the capabilities of the plain timber pile to footing connection and the desired minimum ultimate capacity of a timber pile anchor. Specimen 4C, which had the lowest strength of the two specimens tested statically, had an ultimate tensile strength more than 4 times the 29 kip capacity of the plain timber pile specimen and more than 3 times the desired ultimate capacity of 36 kips for a timber pile anchor to footing connection. Both Specimens 4A and 4C attained their ultimate strengths at a measured slip of approximately 0.095 inch. Loads at other selected slip values are shown in Table 2.

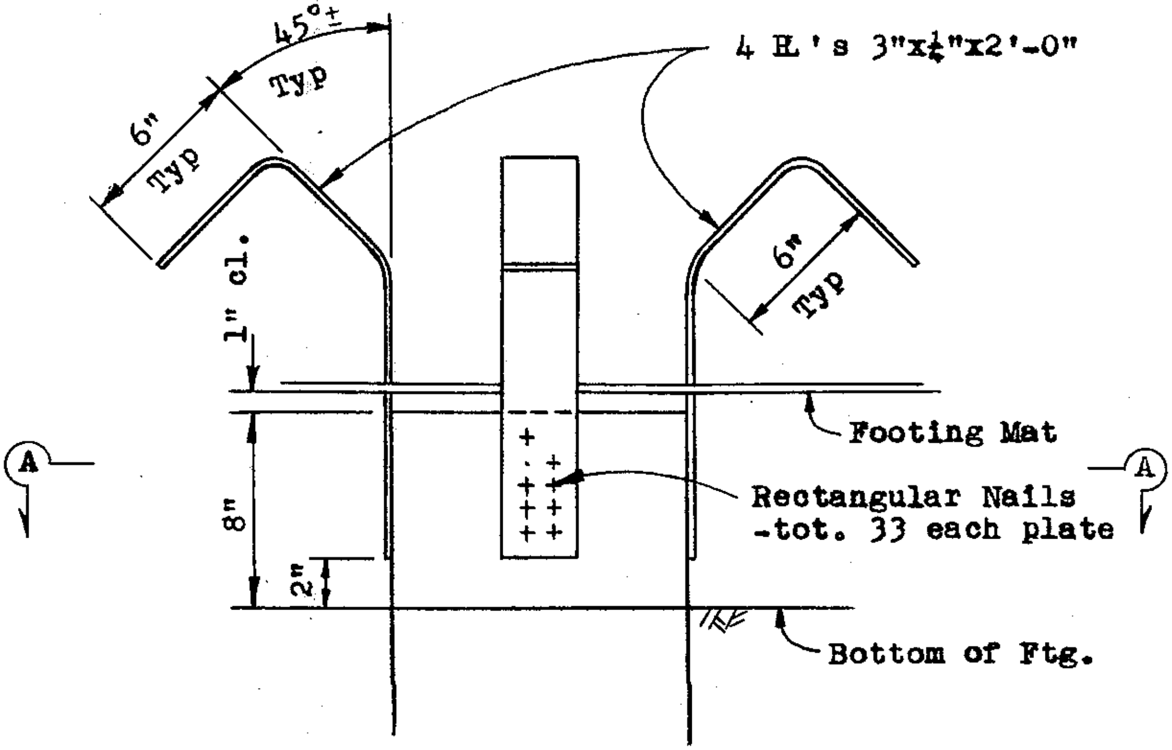
The performance of this anchor during cyclic loading (Specimen 4B) was outstanding as can be seen in the cyclic loading portion of Figure A-23 even though some minor permanent slip did occur during the application of 100 cycles of the 0 to 18.1 kip load range. At the completion of cyclic loading, however, the permanent slip averaged only 0.006 inch for both ends of the specimen. The successive load ranges applied are shown numerically in Table 4. From these results it is apparent that anchor type No. 4 will very readily withstand at least 100 cycles of 0 to 36 kips.

The recovery capability of this anchor after cyclic loading was excellent as demonstrated by the static loading portion of Figure A-23. The final estimated capacity of Specimen 4B was 142+ kips at an average measured slip of 0.10 inch. This is comparable to the results obtained with the purely static load tests (Specimens 4A and 4C). The static reload curve for Specimen 4B closely followed the shape of the curves for Specimens 4A and 4C except that the yield point of Specimen 4B was much more pronounced.



Estimated Cost, Installed:
$16.50

Section A-A



DETAILS FOR
PILE ANCHOR TYPE NO. 4

Figure A-20

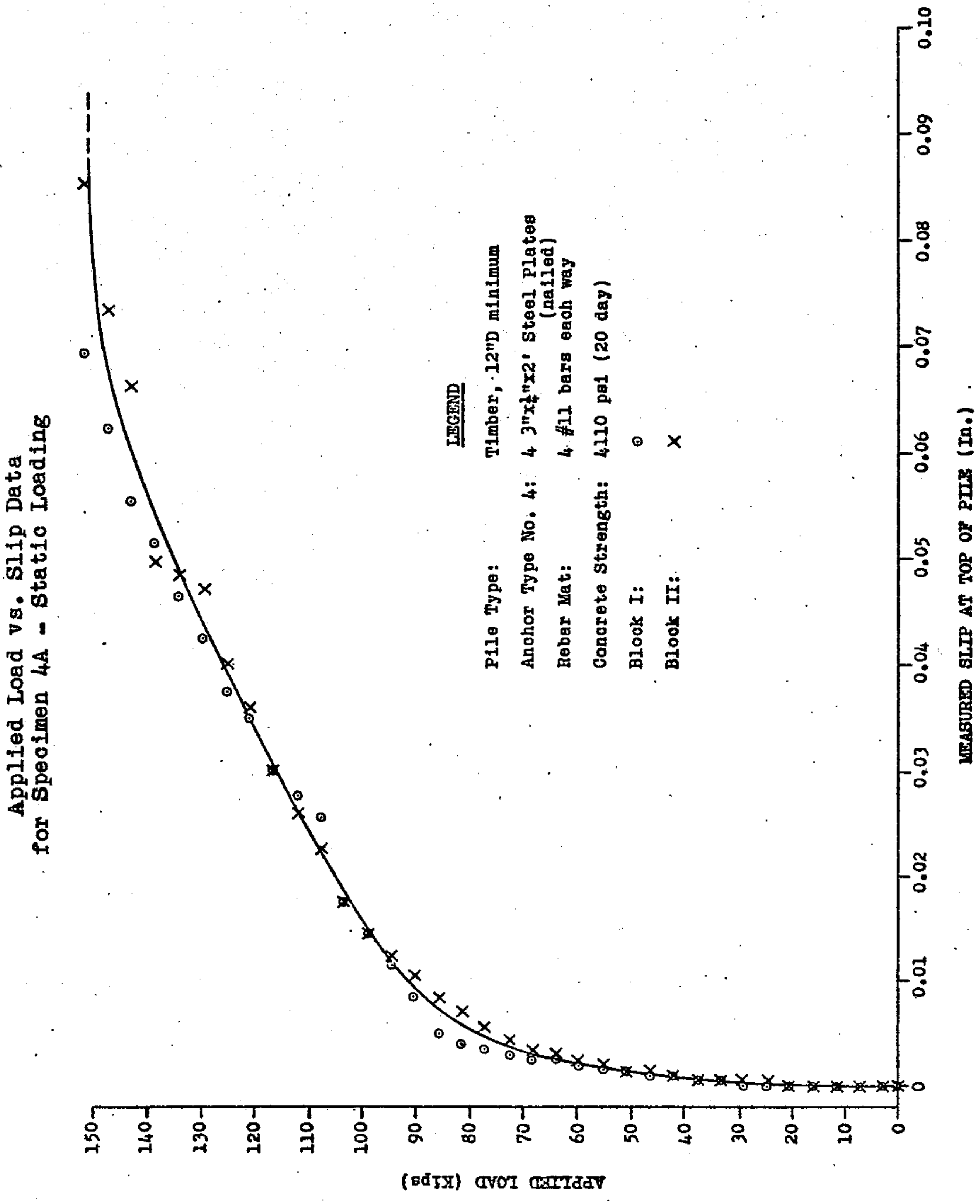

Applied Load vs. Slip Data
for Specimen 4A - Static Loading
LEGEND
Pile Type: Timber, 12"D minimum
Anchor Type No. 4: 4 3"x¼"x2' Steel Plates (nailed)
Rebar Mat: 4 #11 bars each way
Concrete Strength: 4110 psi (20 day)
Block I:
Block II:
APPLIED LOAD (Kips)
MEASURED SLIP AT TOP OF PILE (In.)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

Figure A-21

Applied Load vs. Slip Data
for Specimen 4C - Static Loading

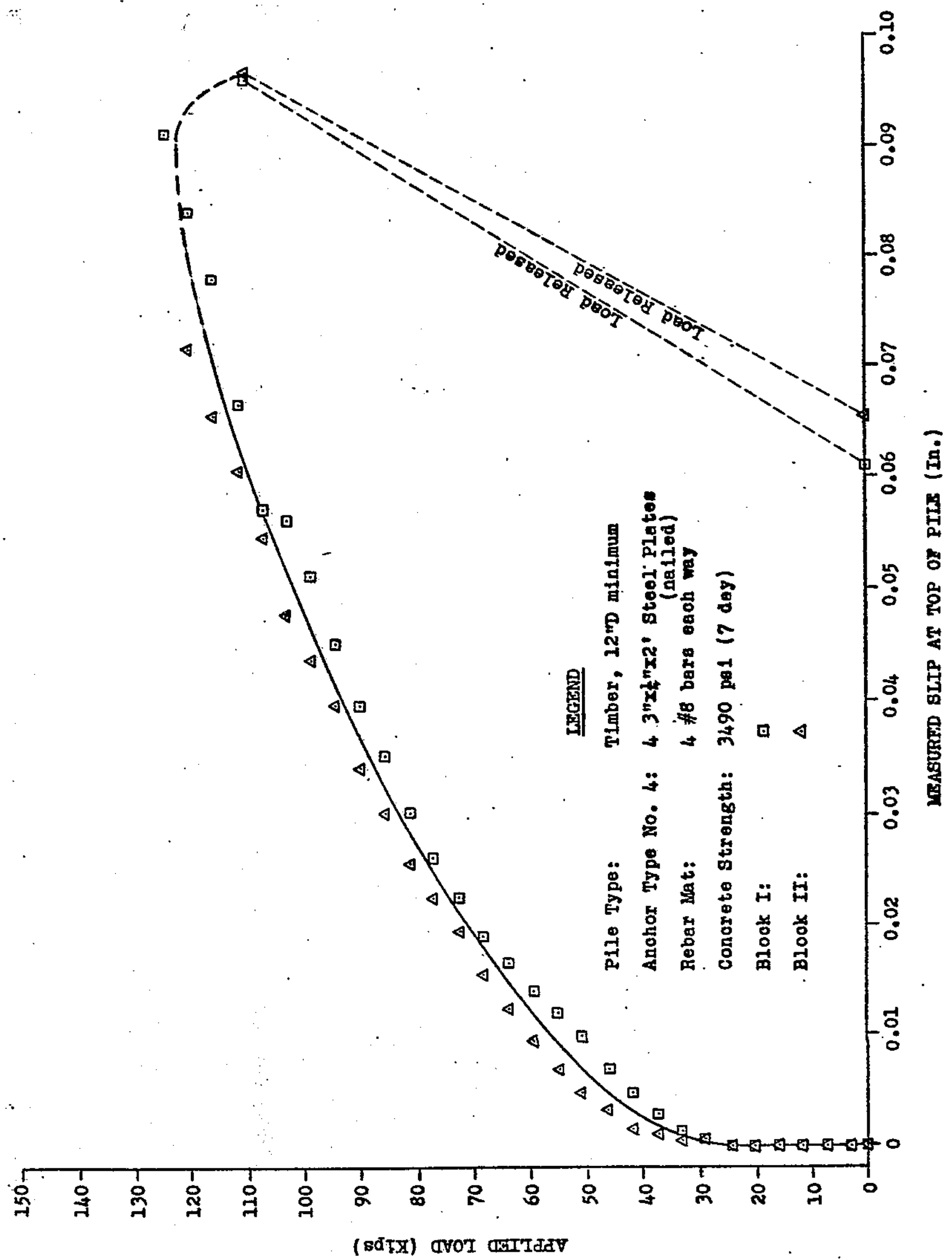


Figure A-22

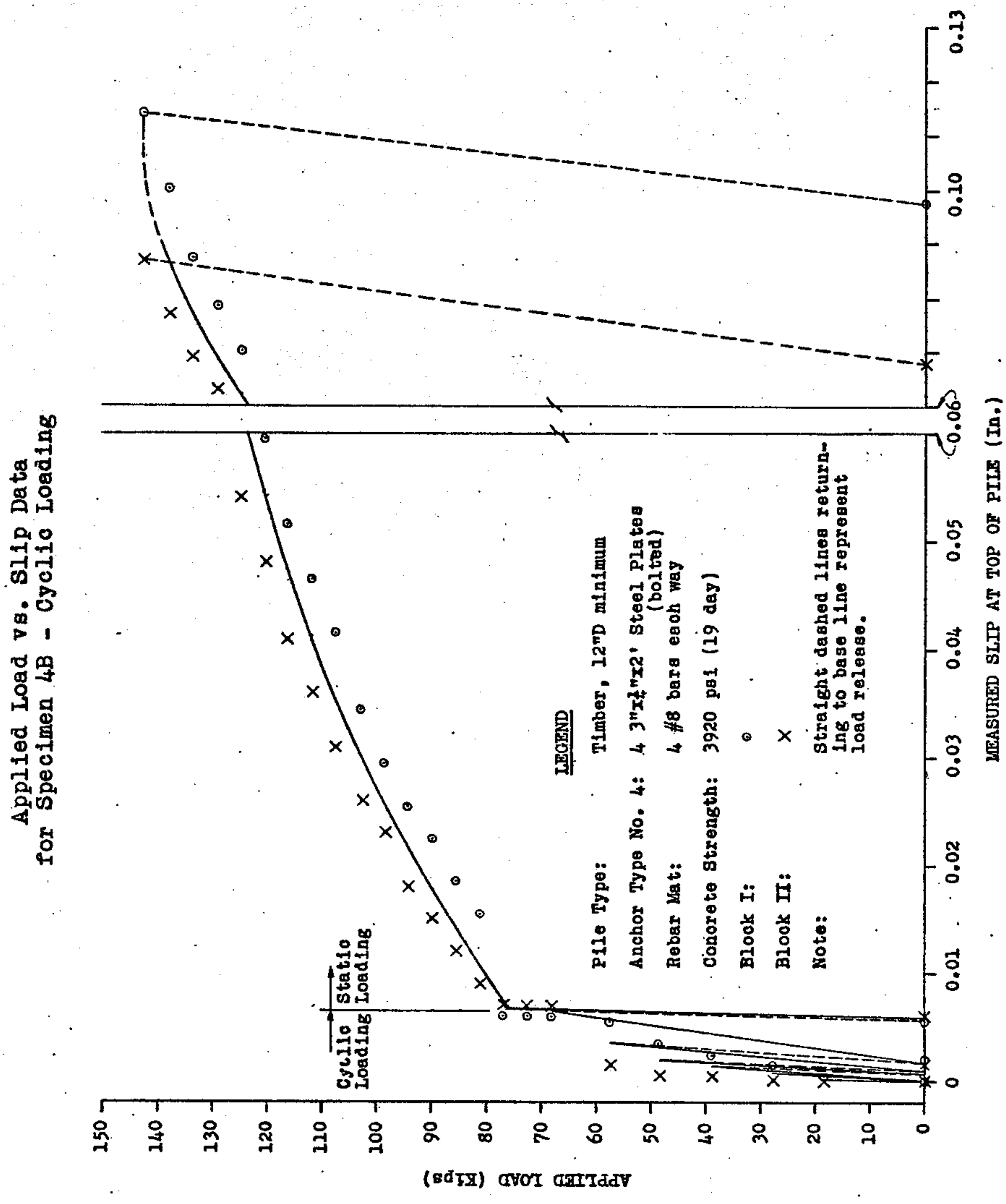

Applied Load vs. Slip Data
for Specimen 4B - Cyclic Loading
APPLIED LOAD (Kips)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
MEASURED SLIP AT TOP OF PILE (In.)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.10
0.13
Cyclic Loading
Static Loading
LEGEND
Pile Type: Timber, 12"D minimum
Anchor Type No. 4: 4 3"x¼"x2' Steel Plates (bolted)
Rebar Mat: 4 #8 bars each way
Concrete Strength: 3920 psi (19 day)
Block I: ⊙
Block II: X
Note: Straight dashed lines returning to base line represent load release.

Figure A-23

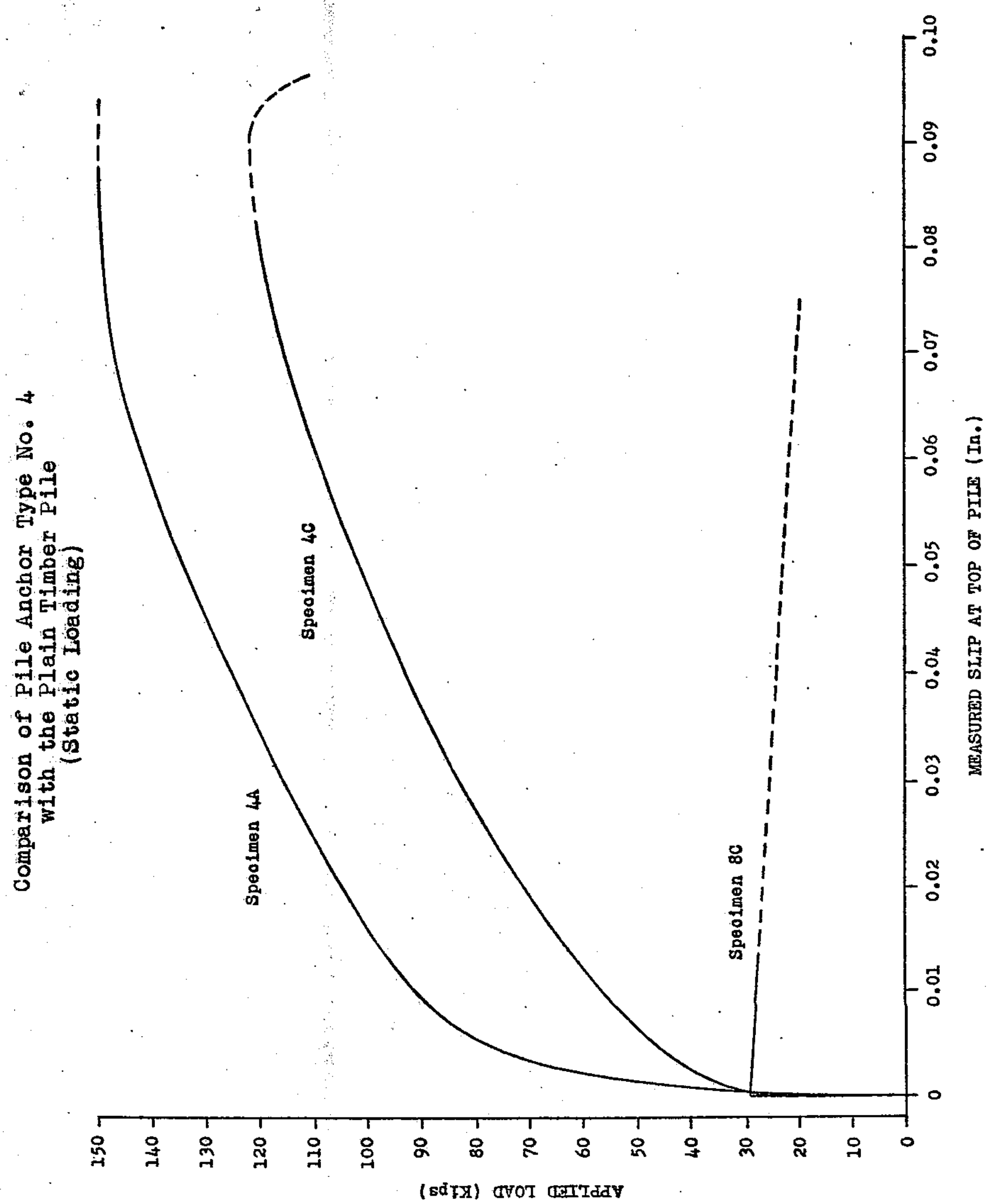

Comparison of Pile Anchor Type No. 4
with the Plain Timber Pile
(Static Loading)
Specimen 4A
Specimen 4C
Specimen 8C
APPLIED LOAD (Kips)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
MEASURED SLIP AT TOP OF PILE (In.)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

Figure A-24

Anchor Type No. 5

Pile anchor type No. 5 consists of 2 #4 and 4 #6 concrete reinforcing steel bars placed around the notched end of the pile as shown in the anchor details in Figure A-25.

The results of the load tests on Specimens 5A, 5C and 5B are presented graphically in Figures A-26, A-27, A-28 and A-29. The results from the two ends of Specimen 5A were very consistent. However, the anchor in Block II of Specimen 5C began yielding at a much lower load than the anchor in Block I of the specimen. It appears that some anomaly in the Block II anchor caused the discrepancy in results since the results from Block I agree closely with those from Specimen 5A up to a load of 45 kips. It could not be determined what caused this discrepancy by examining Specimen 5C after testing. It must therefore be assumed that this is the normal variation to be expected when this type of anchor is used.

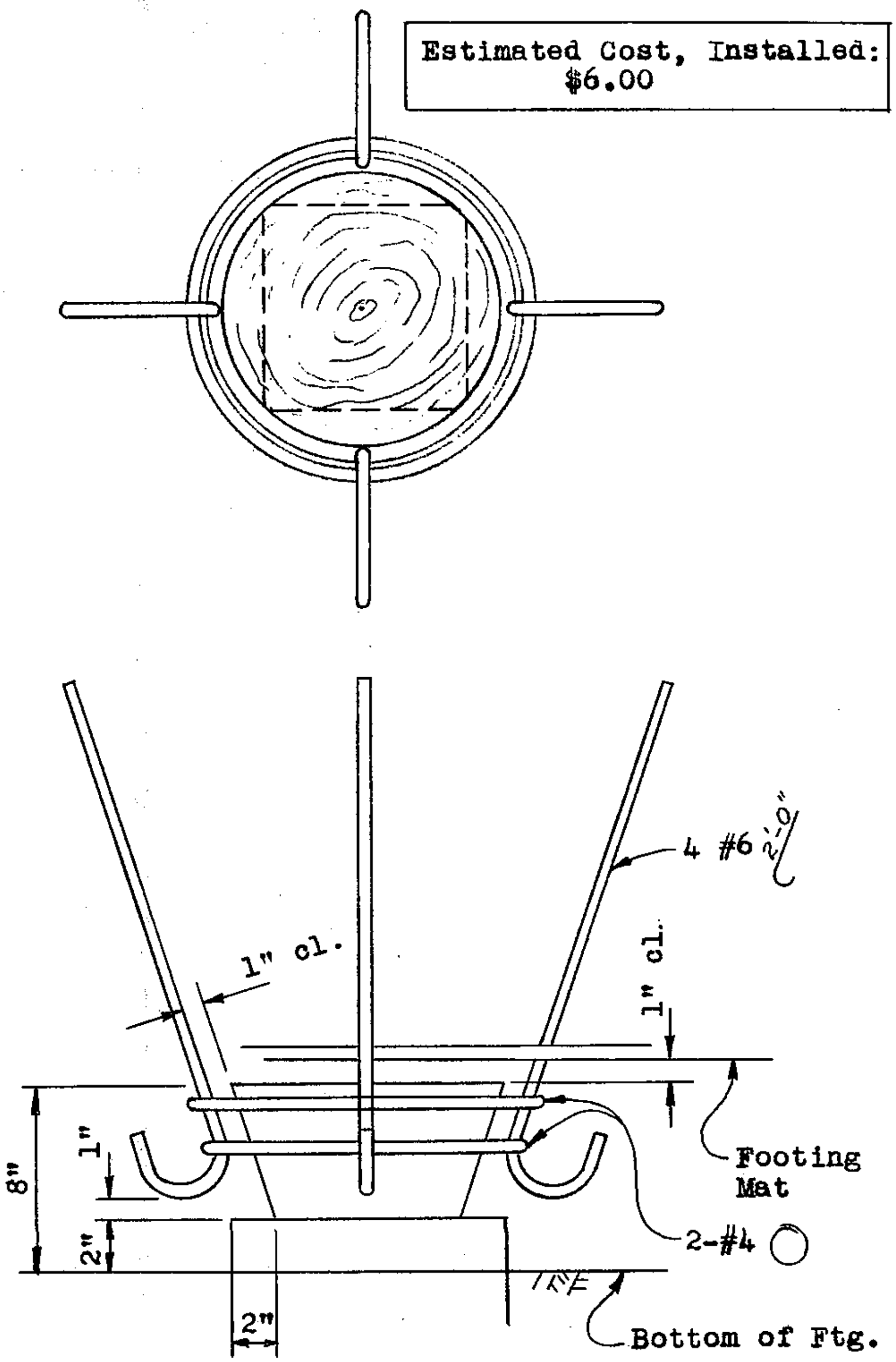
Table 2 shows the ultimate load capacity and the loads at various slip values for the three specimens containing this anchor. Due to the variation in results discussed above, both the maximum and minimum loads as well as the value on the load vs. average slip curve are given for Specimen 5C. Note that even with the much lower yield point of anchor No. II of Specimen 5C, the ultimate capacities of the two anchors in this specimen were both 76 kips, although ultimate was attained at much different slip values.

As shown in Table 2 the ultimate load capacity of the Specimen 5A anchors was 63 kips, 13 kips less than the capacity of the Specimen 5C anchors. This is nearly twice the desired ultimate capacity of 36 kips and more than twice the 29 kips actual load capacity of a plain timber pile. The load vs. slip curves for Specimen 5A, 5C and the control Specimen 8C are compared in Figure A-29. As with all of the anchors previously discussed, anchor type No. 5 is capable of resisting loads near ultimate without a sudden failure of the pile to footing connection. However, due to the configuration of the anchor the mode of failure is slightly different than with the other anchors as previously shown in Figure A-3.

Anchor type No. 5 performed very well under cyclic loading as shown in Figure A-28 and Table 4. No permanent slip occurred until after 100 cycles of 0 to 27.9 kips had been applied, and then the slip was only minor. Continuously increasing slip measurements during application of the 0 to 68.2 kip load range indicated that the specimen was on the verge of failure. Loading was discontinued after 46 cycles of the final loading, but the final permanent slip after load release was less than 0.001 inch. From Figure A-28 it is clear that this anchor will readily resist 100 cycles of 0 to 36 kips.

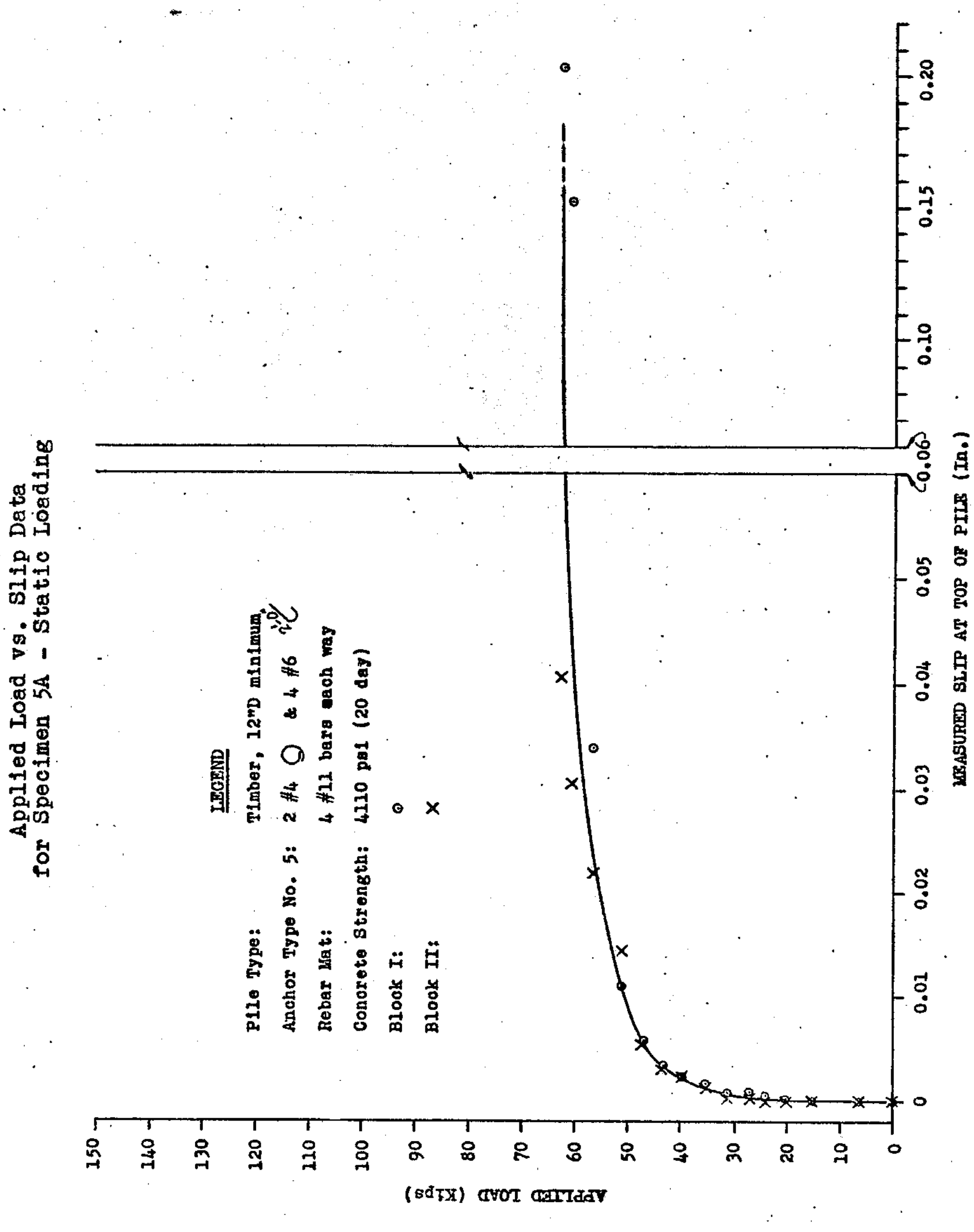
Specimen 5B was not reloaded statically after completion of the cyclic loading. It is estimated however, that the specimen would have withstood at least 50 kips during static reloading.

Estimated Cost, Installed: $6.00



DETAILS FOR
PILE ANCHOR TYPE NO. 5

Figure A-25



Applied Load vs. Slip Data
for Specimen 5A - Static Loading
LEGEND
Pile Type: Timber, 12"D minimum
Anchor Type No. 5: 2 #4 & 4 #6
Rebar Mat: 4 #11 bars each way
Concrete Strength: 4110 psi (20 day)
Block I:
Block II:
APPLIED LOAD (Kips)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
MEASURED SLIP AT TOP OF PILE (In.)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.10
0.15
0.20

Figure A-26

Applied Load vs. Slip Data
for Specimen 5C - Static Loading

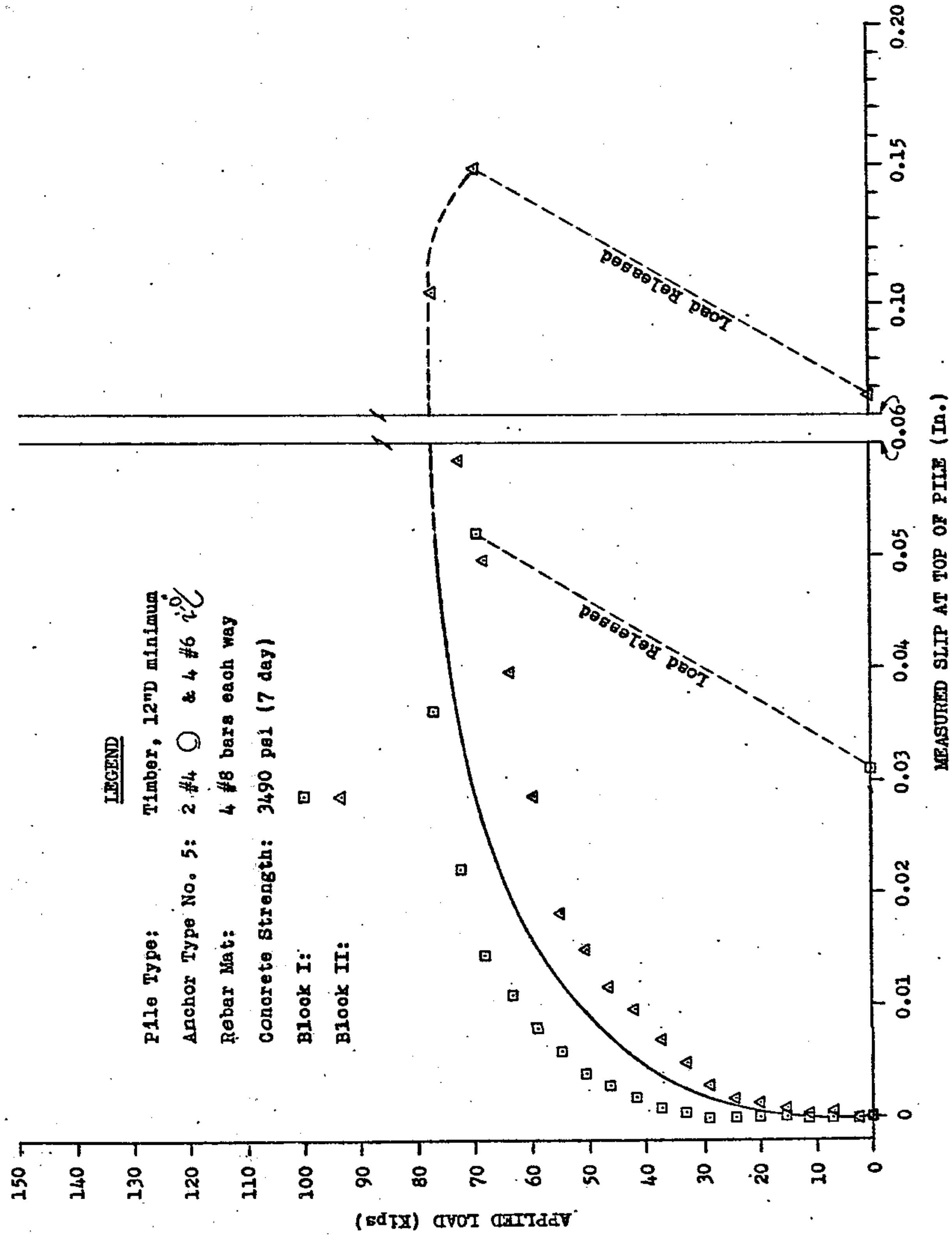


Figure A-27

Applied Load vs. Slip Data for Specimen 5B - Cyclic Loading

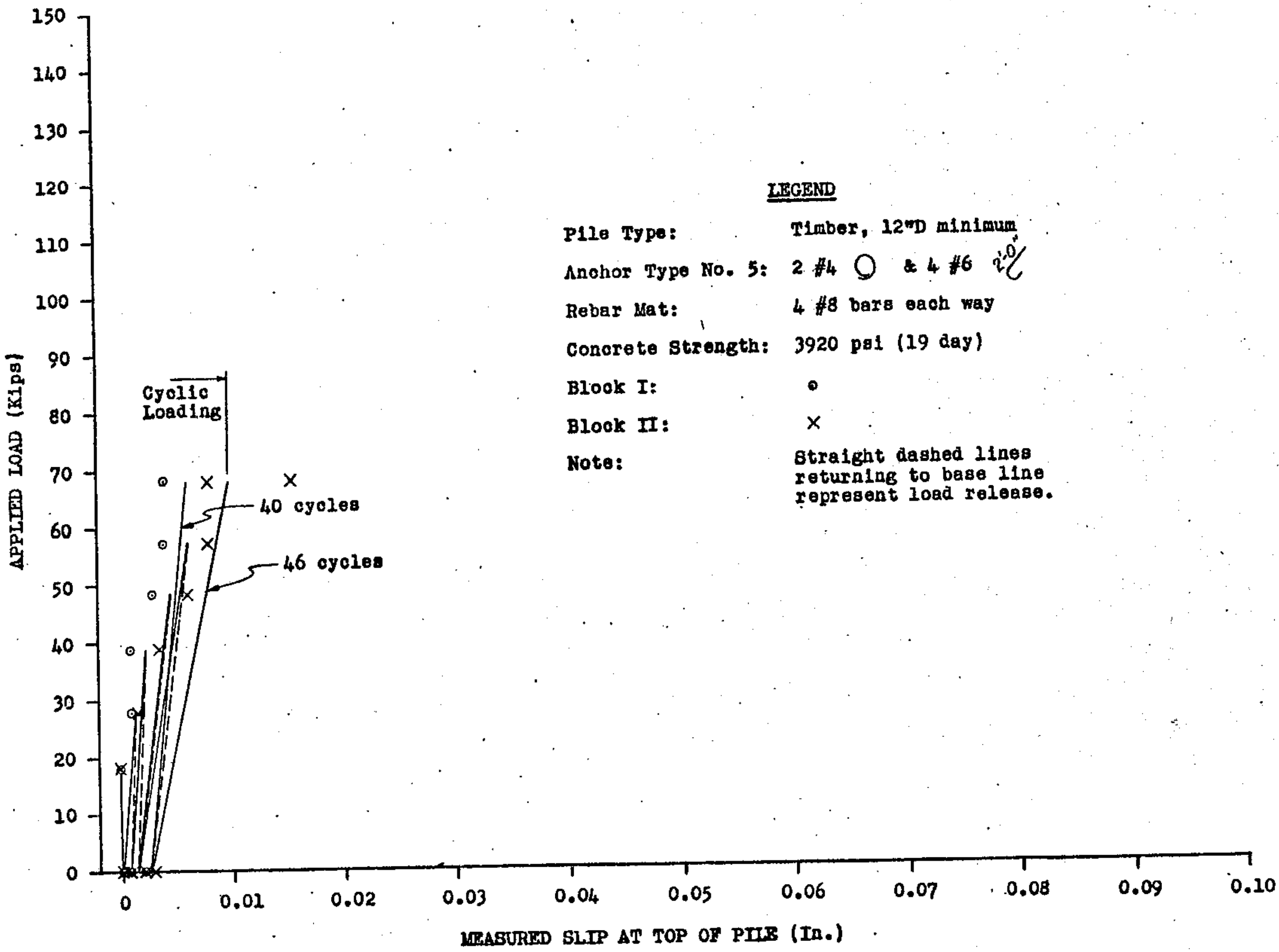


Figure A-28

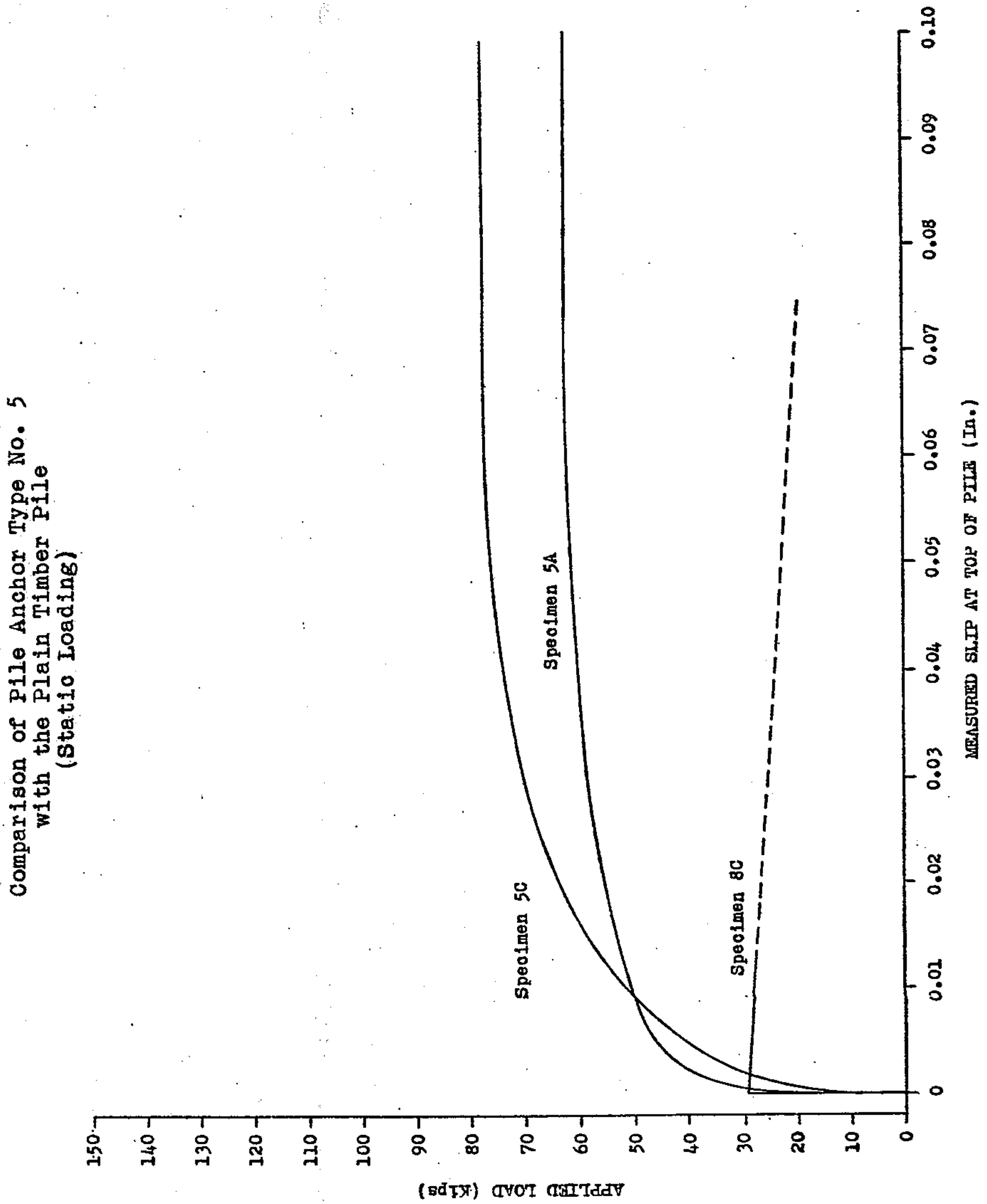

Comparison of Pile Anchor Type No. 5
with the Plain Timber Pile
(Static Loading)
Specimen 5A
Specimen 5C
Specimen 8C
APPLIED LOAD (Kips)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
MEASURED SLIP AT TOP OF PILE (In.)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

Figure A-29

Anchor Type No. 6

Pile anchor type No. 6 consists primarily of 2 2'-6"x3/4" hooked rods extending through holes drilled in the end of the pile at an angle and fastened with nuts as shown in Figure A-30. Two variations of the anchor were tested, the difference being in the type of bearing plate under the nut. For all three test specimens a steel angle iron was used as the bearing plate in Block I, and a metal washer was used as the bearing plate in Block II.

Graphical presentations of the data obtained from the three tests are shown in Figures A-31, A-32, A-33 and A-34. Again loads at various selected slip values and a numerical summary of the cyclic load data are shown in Tables 2 and 4 respectively.

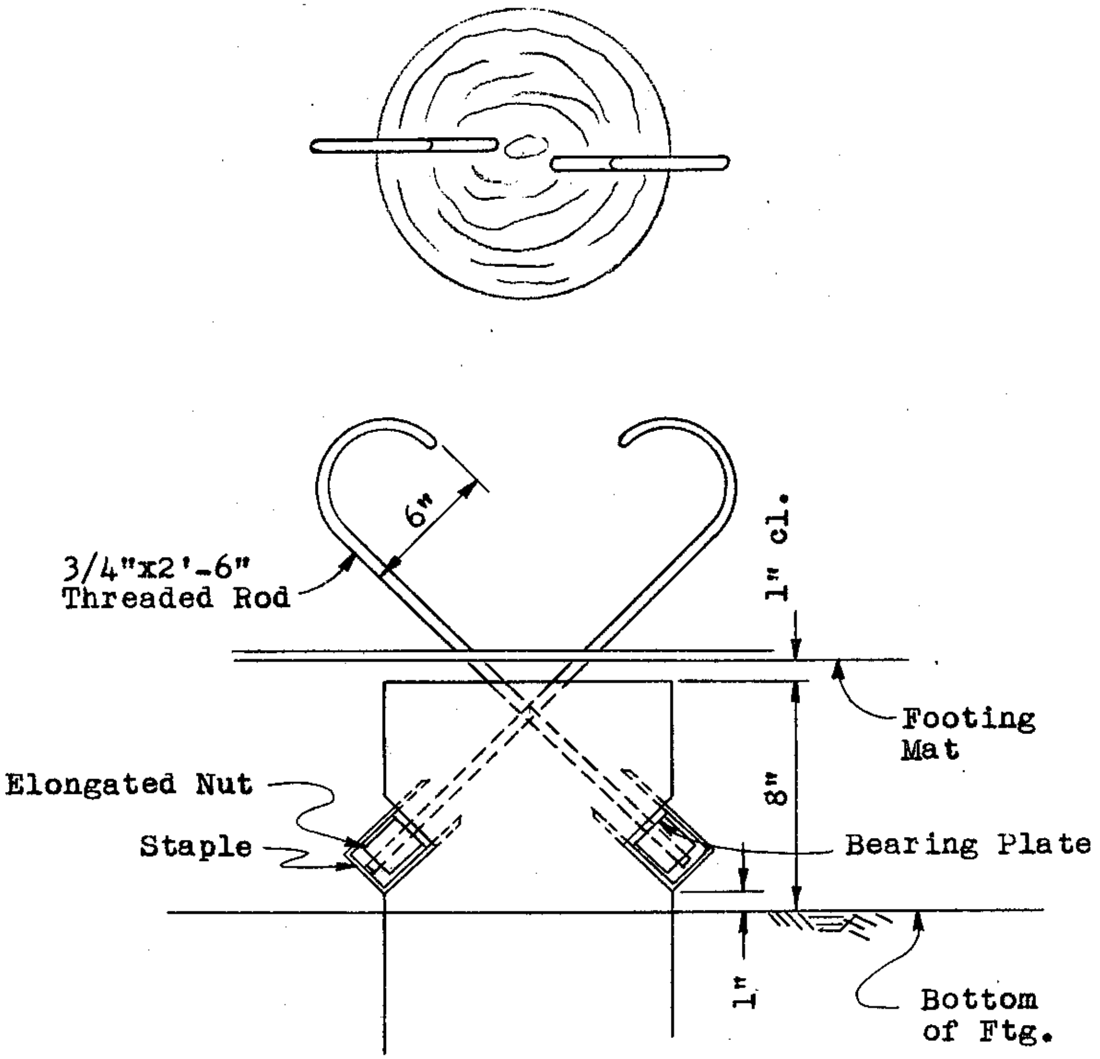
The ultimate strengths of both variations of this anchor are nearly identical, but variation No. I with the angle iron bearing plate is superior to variation No. II when loaded statically. In both tests 6A and 6C variation No. II failed rather suddenly when its ultimate capacity was reached while variation No. I yielded a considerable amount prior to the point where it would no longer sustain a load.

Figures A-35 and A-36 compare the load vs. slip curves of both anchor variations with the curves for the control specimen 8C. It is clear that neither variation of anchor type No. 6 can be consistently relied on to be much more effective in developing the pile to footing connection than the plain timber pile. The capacity of both anchors in Specimen 6C is 32 kips. This is only slightly greater than the 29 kip capacity of the plain timber pile and 4 kips less than the desired minimum ultimate capacity of the pile to footing connection of 36 kips. The behavior of both variations of this anchor under cyclic loading appears adequate since both are capable of resisting 100 cycles of 0 to 36 kip loading. These results are shown in the first portion of Figures A-33 and A-34. Variation No. II with the metal washer bearing plate was superior however, to variation No. I with the steel angle bearing plate. First permanent slip, though minor, was noted for both variations of the anchor after 100 cycles of the 0 to 18.1 kip loading. Variation No. I was on the verge of failure 25 cycles into the 48.6 kip load range with a permanent slip of 0.042 inch while variation No. II was able to withstand this loading without appreciable permanent slip. Cyclic loading could not be continued beyond this point for variation No. II due to the large movements occurring with variation No. I at the other end of the specimen.

Upon reloading Specimen 6B statically at the completion of cyclic loading as shown in the second portion of Figures A-33 and A-34, variation No. I failed at a load of 55 kips. It appears from Figure A-34 that the reload capacity of variation No. II would be greater than 55 kips.

NOTE: Variation I of this anchor has a steel angle iron bearing plate while Variation II has a metal washer bearing plate.

Estimated Cost, Installed:	
Variation I	Variation II
$9.50	$6.50



DETAILS FOR
PILE ANCHOR TYPE NO. 6

Figure A-30

Applied Load vs. Slip Data
for Specimen 6A - Static Loading

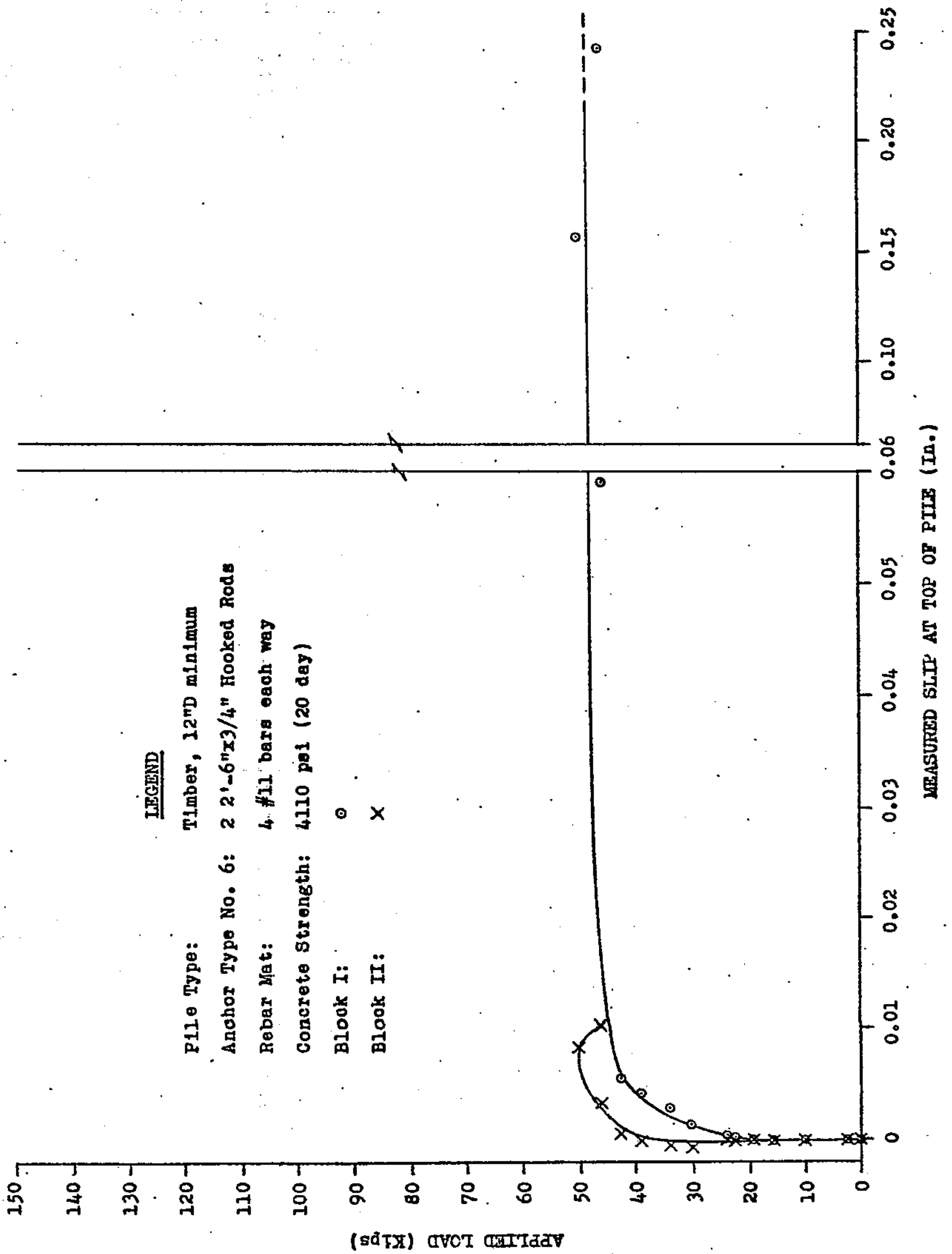


Figure A-31

Applied Load vs. Slip Data
for Specimen 6C - Static Loading

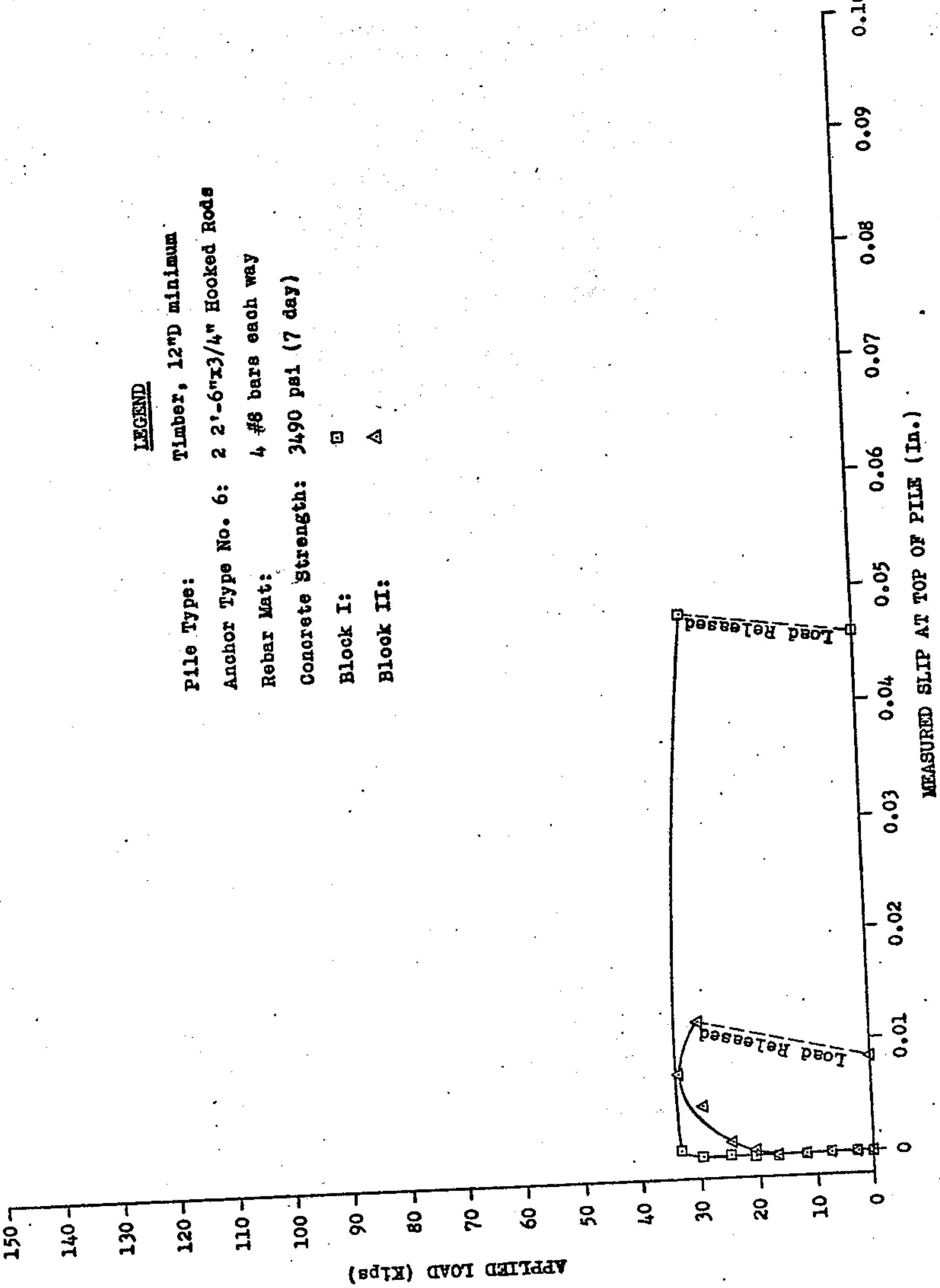


Figure A-32

Applied Load vs. Slip Data
for Specimen 6B (Variation I) - Cyclic Loading

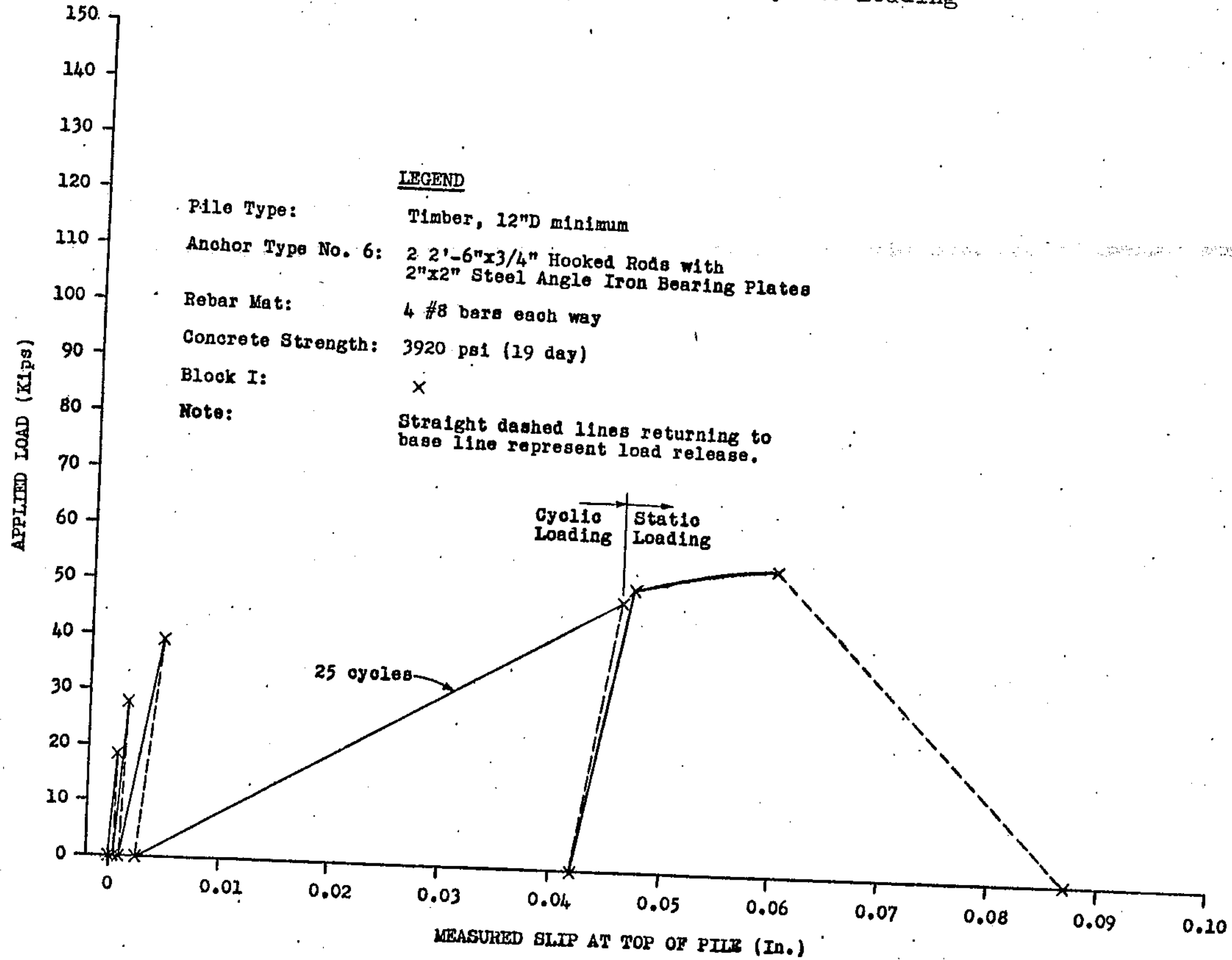


Figure A-33

Applied Load vs. Slip Data
for Specimen 6B (Variation II) - Cyclic Loading

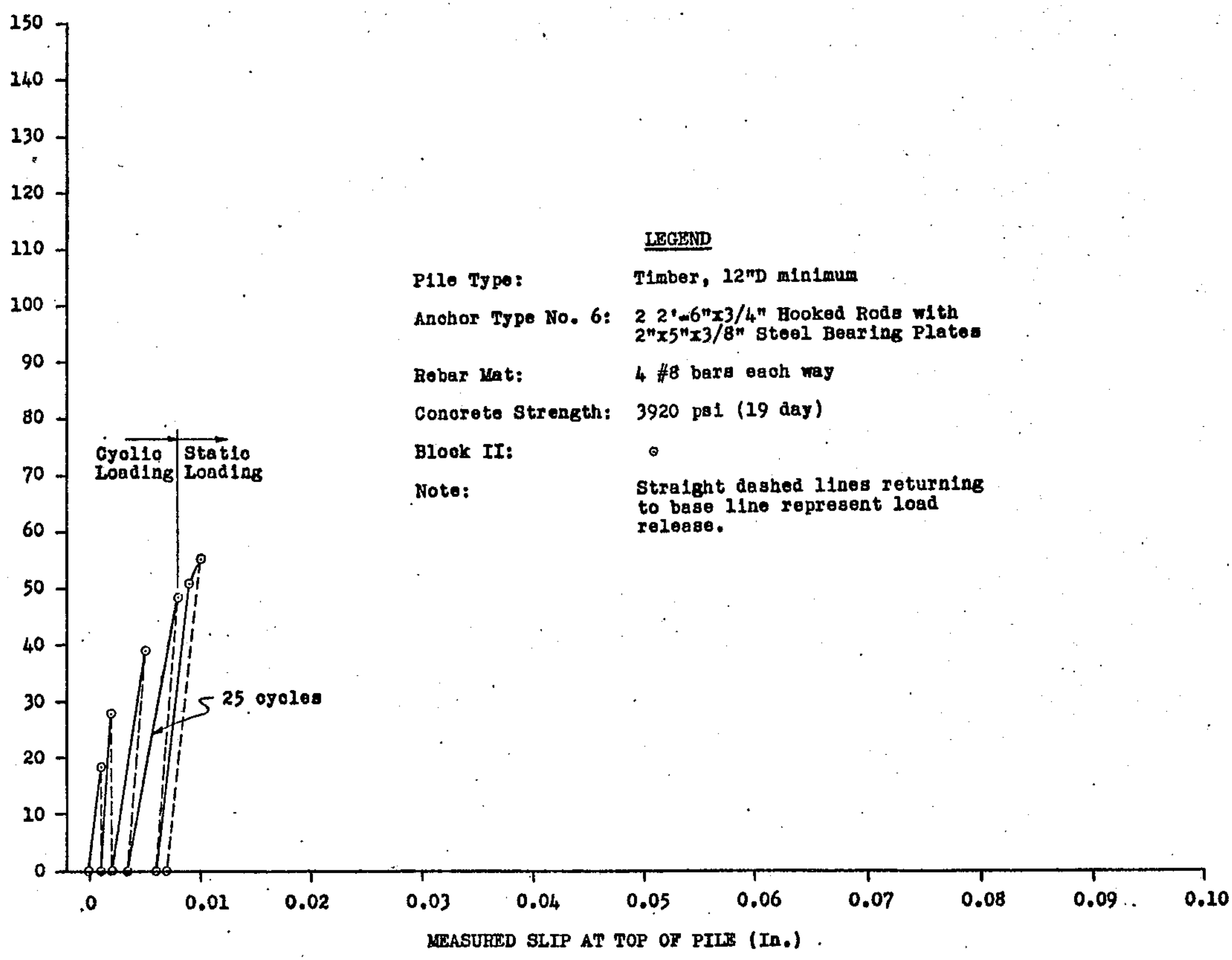


Figure A-34

Comparison of Pile Anchor Type No. 6 (Variation I) with the Plain Timber Pile (Static Loading)

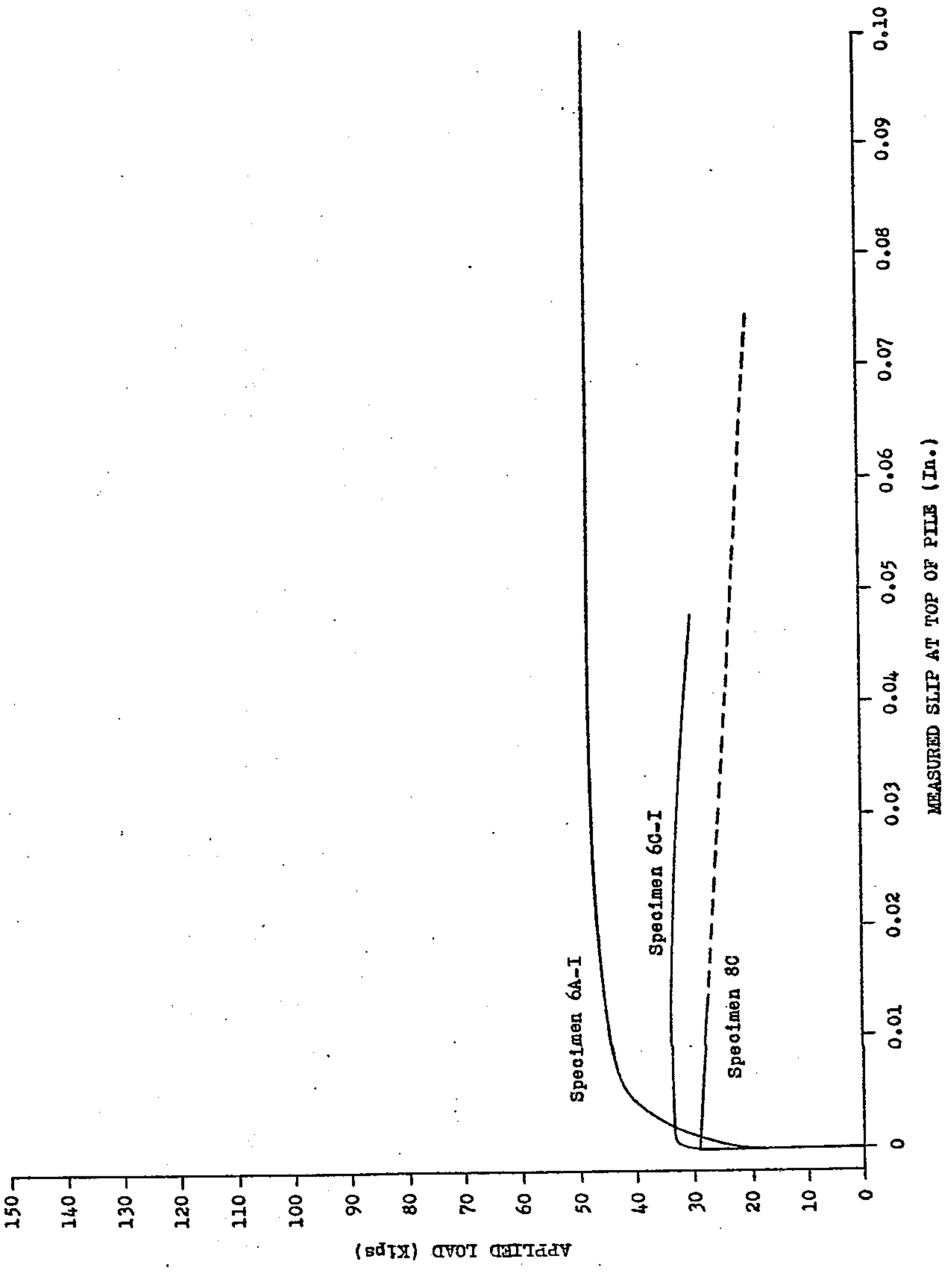


Figure A-35

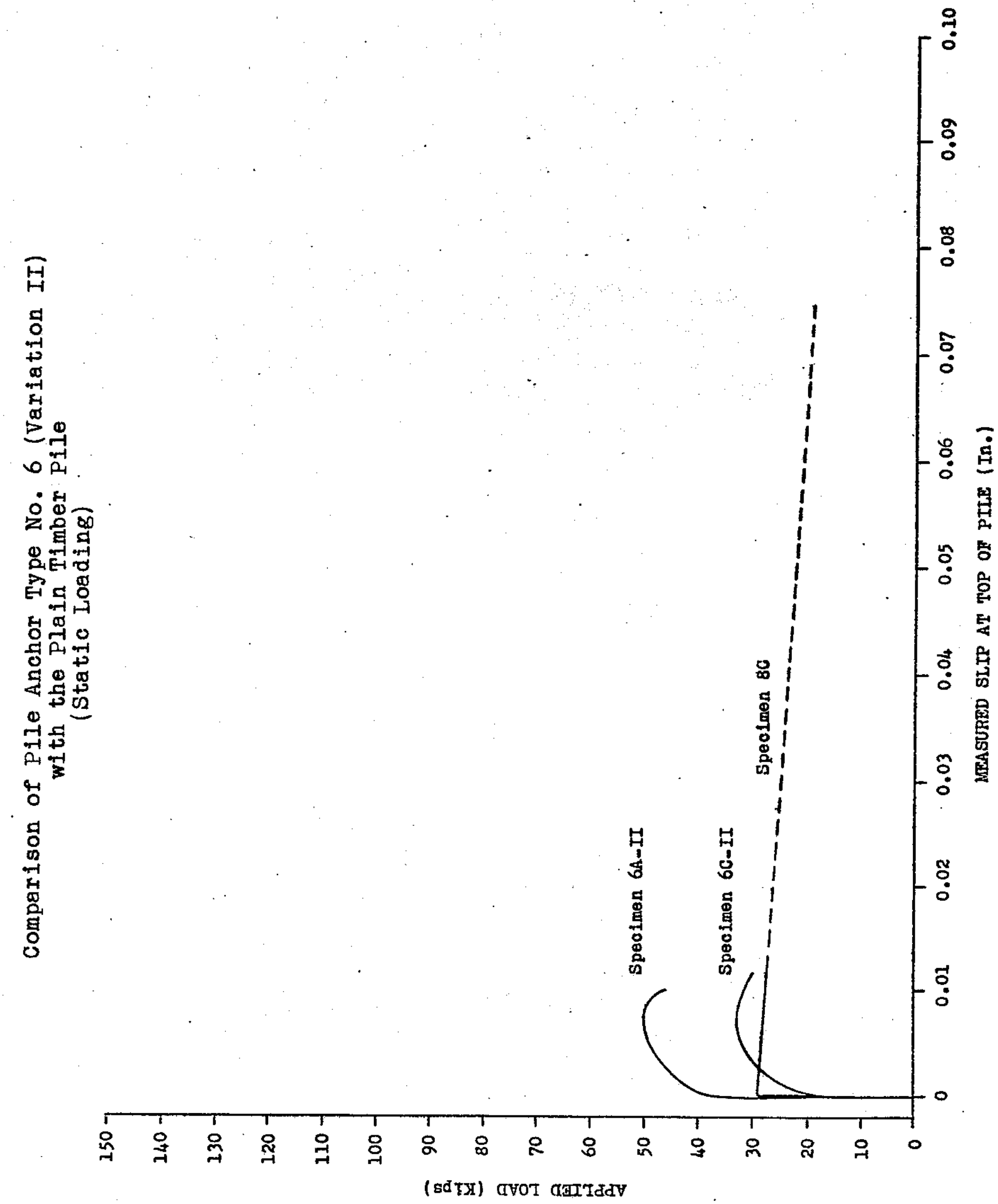

Comparison of Pile Anchor Type No. 6 (Variation II)
with the Plain Timber Pile
(Static Loading)
Specimen 6A-II
Specimen 6C-II
Specimen 8G
APPLIED LOAD (Kips)
MEASURED SLIP AT TOP OF PILE (In.)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10

Figure A-36

SUMMARY GRAPHS

Summaries of the results from test series A and test series C are given in Figures A-37 and A-38. Summaries of the results from test series B are given in Figures A-39 and A-40.

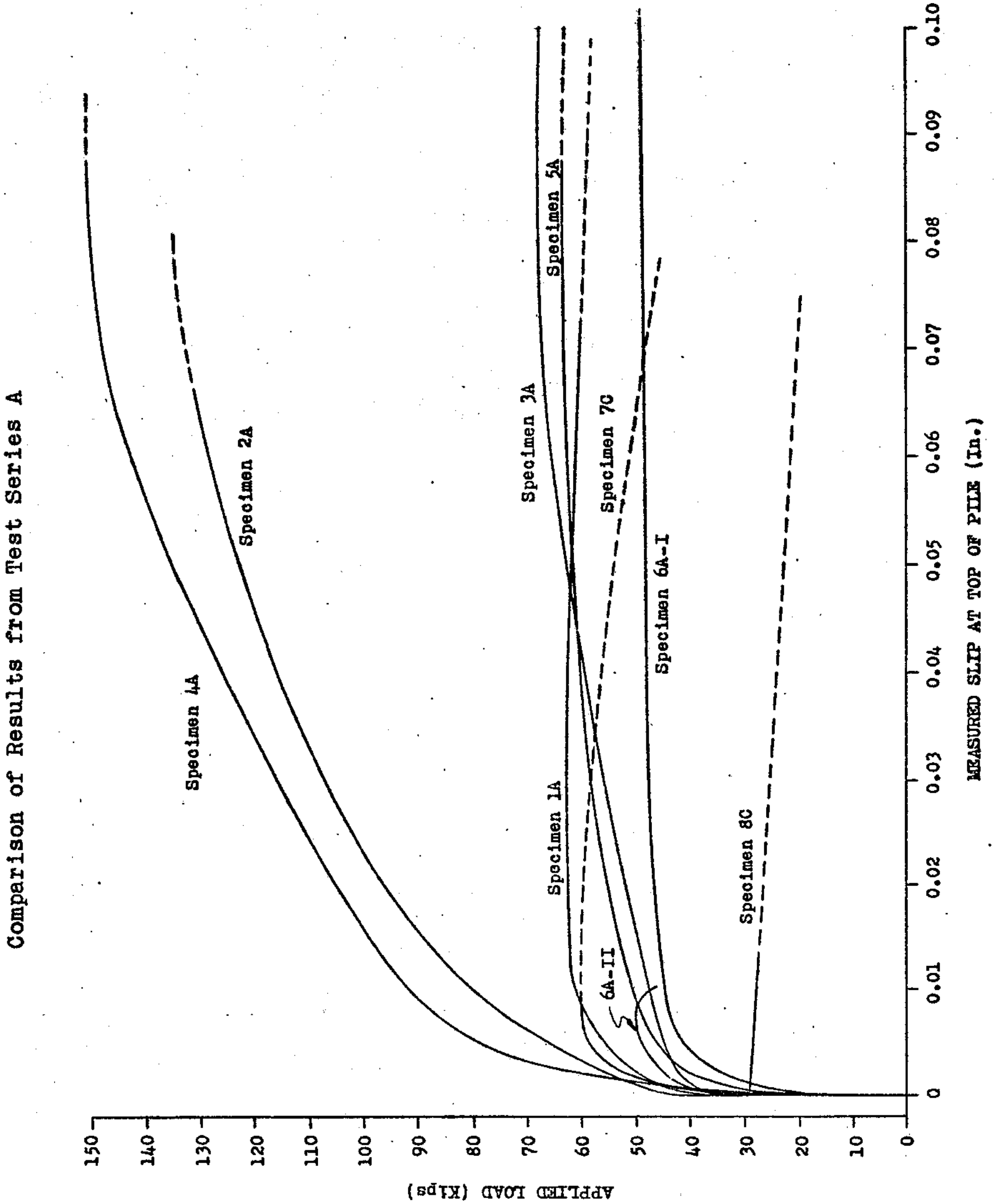
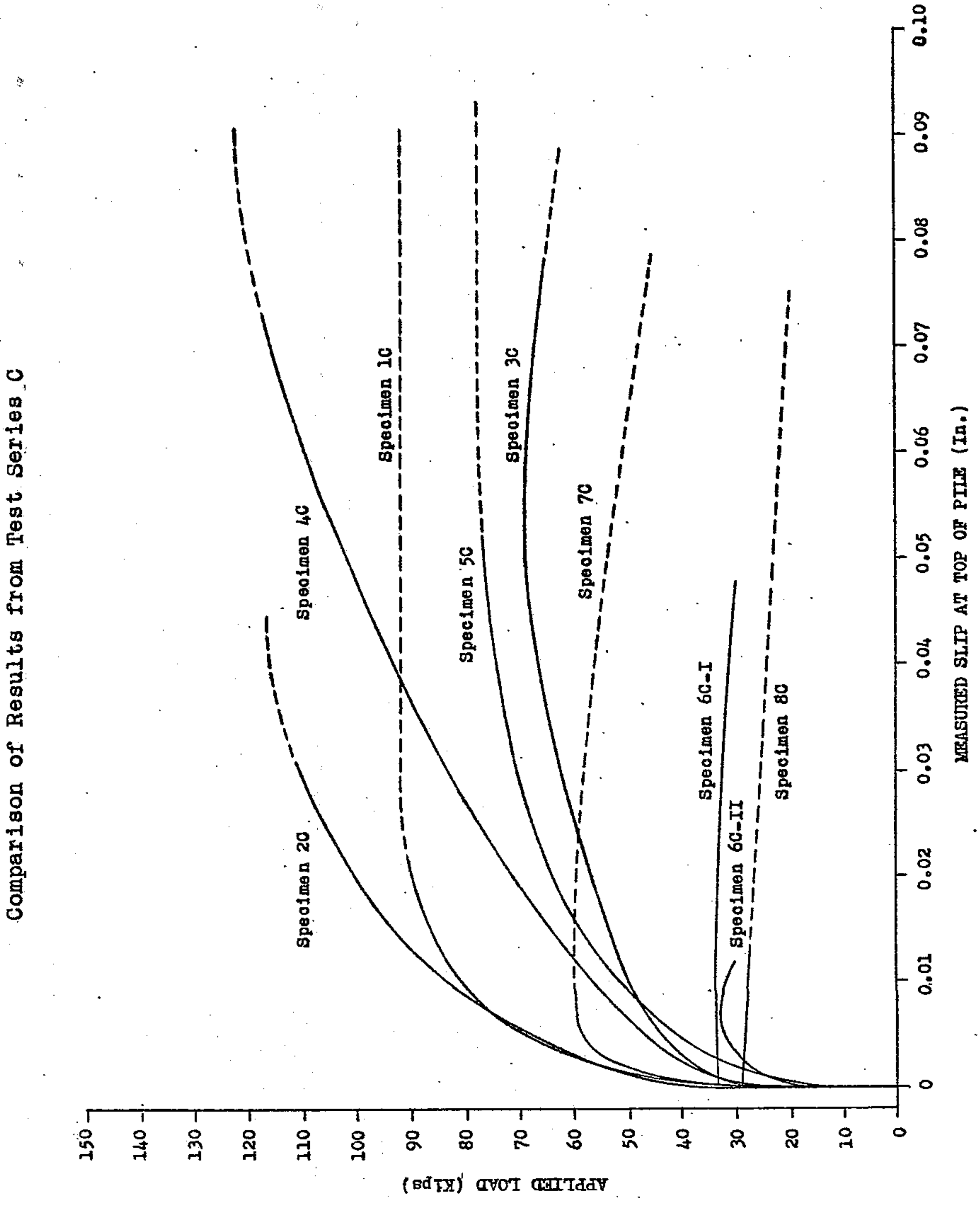

Comparison of Results from Test Series A
Specimen 4A
Specimen 2A
Specimen 3A
Specimen 5A
Specimen 7C
Specimen 6A-I
Specimen 1A
6A-II
Specimen 8C
MEASURED SLIP AT TOP OF PILE (In.)
APPLIED LOAD (Kips)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

Figure A-37



Comparison of Results from Test Series C
Specimen 1C
Specimen 2C
Specimen 3C
Specimen 4C
Specimen 5C
Specimen 6C-I
Specimen 6C-II
Specimen 7C
Specimen 8C
APPLIED LOAD (Kips)
MEASURED SLIP AT TOP OF PILE (In.)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

Figure A-38

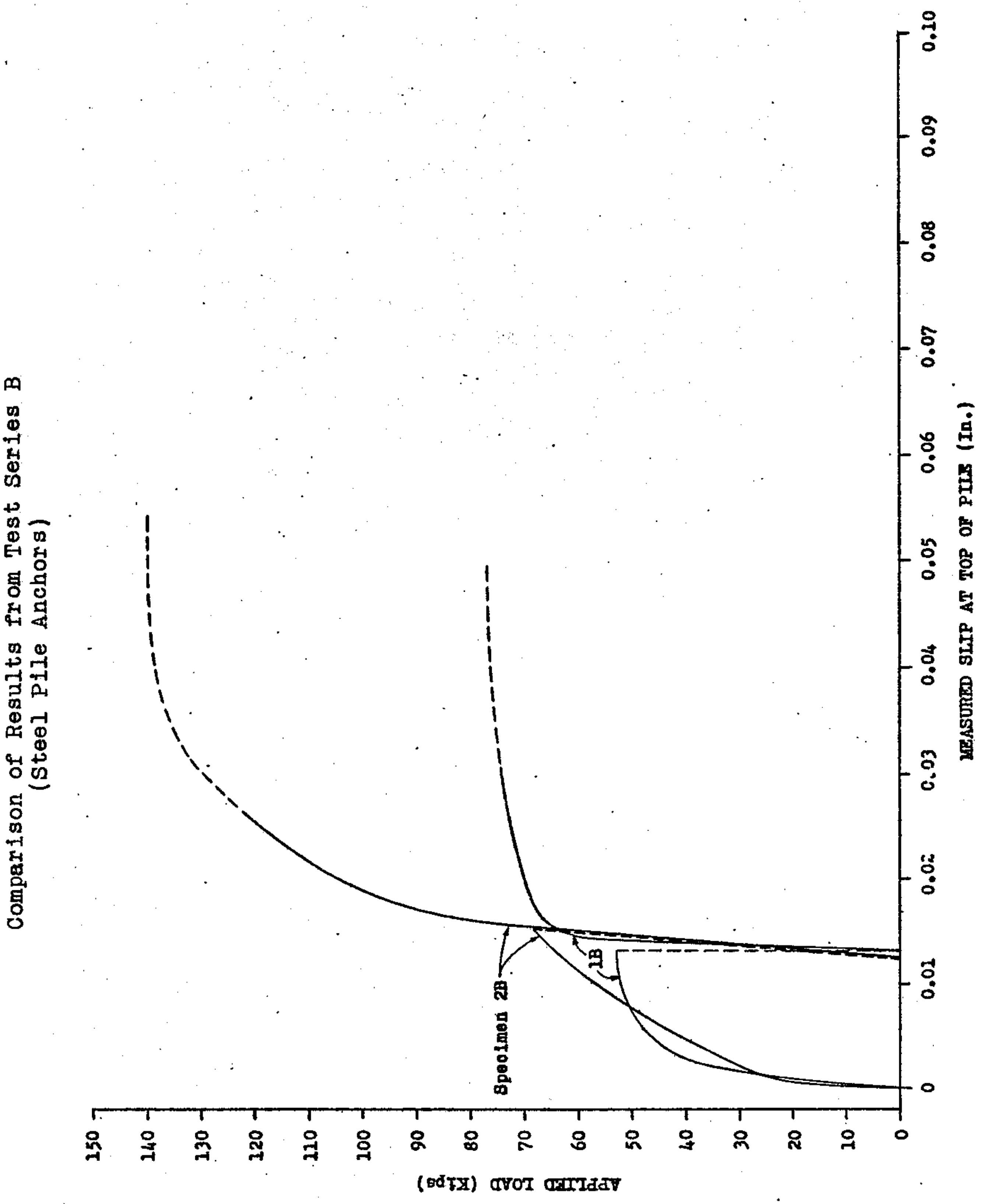

Comparison of Results from Test Series B
(Steel Pile Anchors)
Specimen 2B
1B
APPLIED LOAD (Kips)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
MEASURED SLIP AT TOP OF PILE (In.)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

Figure A-39

Comparison of Results from Test Series B
(Timber Pile Anchors)

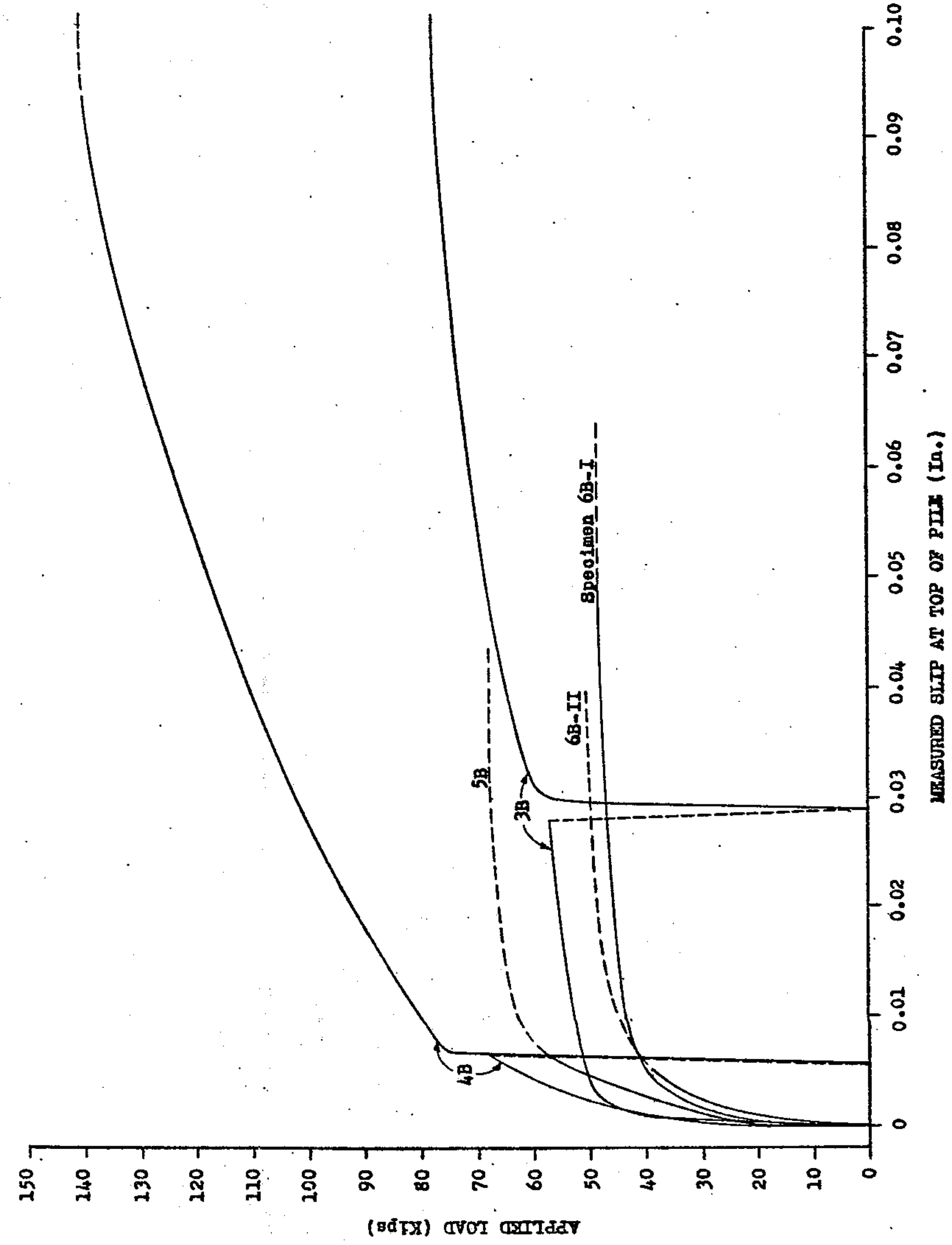


Figure A-40